10 APRIL 1979

PHYSICAL SCIENCES AND TECHNOLOGY
(FOUO 19/79)

1 OF 2

FOR OFFICIAL USE ONLY

JPRS L/8387

10 April 1979

USSR

TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY
PHYSICAL SCIENCES AND TECHNOLOGY
(FOUO 19/79)

U. S. JOINT PUBLICATIONS RESEARCH SERVICE

FOR OFFICIAL USE ONLY

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattributed parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

JPRS L/8387

10 April 1979

TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY

PHYSICAL SCIENCES AND TECHNOLOGY

(FOUO 19/79)

CONTENTS

PAGE

CONTENTS (Continued) Page

CONTENTS (Continued)

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.396.96

THE LAW GOVERNING THE DISTRIBUTION OF THE ERROR IN THE MEASUREMENT OF THE RADAR CHARACTERISTICS OF COMPLEX OBJECTS, DUE TO THE SPHERICITY OF THE FRONT OF THE IRRADIATING WAVE

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 15-21

[Article by Yu.A. Kuznetsov, V.A. Melititskiy and V.M. Shlyakhin, manuscript received 20 July, 1977]

[Text] *The formulation of the problem.* Let $X^o(\alpha)$ be any characteristic of an object measured when it is irradiated with a spherical wave, and $X^p(\alpha)$ is the corresponding characteristic of the same object, measured when irradiated with a plane wave. We shall take the measurement error to be the difference $\Delta X(\alpha) = X^o(\alpha) - X^p(\alpha)$.

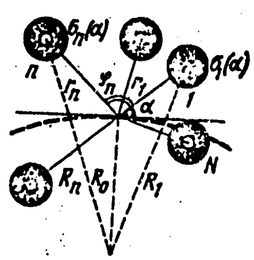


Figure 1.

When processing the results of measurements of the radar characteristics (RLKh) of objects, the random nature of the signal parameter scattered by the target under real conditions, is taken into account, and the static radar characteristics are computed. For this reason, we assume that the object irradiation angle α is random.

$$W(\alpha) = \frac{\exp[d\cos(\alpha-\alpha_0)]}{2\gamma_0 I_0(d)}, \quad \gamma_0 \leqslant \pi, \tag{1}$$

where $W(\alpha)$ is the law governing the distribution of the random irradiation angle; $I_0(d)$ is a modified Bessel function, d and α_0 are the dispersion and mean value of the random parameter α; γ_0 is the averaging interval.

If the illumination angle of the object is random, then the error in the measurement of its radar characteristics should also be described by statistical characteristics: the mean value $\langle \Delta X \rangle$, the dispersion $D\{\Delta X\}$ and the governing distribution law $W(\Delta X)$.

We shall assume that the complex radar object takes the form of a set of coupled reflectors with specified scattering properties (Figure 1), while the field scattered by the object when irradiated with a spherical wave is the result of the superposition of the fields scattered by each elementary reflector, i.e.,

$$E_{\Sigma}^{0}=\sum_{n=1}^{N}\sqrt{\sigma_n(\alpha)}\,e^{i[2kR_n(\alpha)+\beta_n(\alpha)]}, \tag{2}$$

where $\sigma_n(\alpha)$ is the monostatic secondary radiation pattern of the n-th reflector; $\beta_n(\alpha)$ is the phase pattern of the n-th reflector; $R_n(\alpha)$ is the distance from the irradiation source to the n-th reflector; and N is the number of reflectors.

Let us assume that the linear dimensions of each reflector composing the system permit the assumption that the incident wave on it is locally plane. Then $\sigma_n(\alpha)$ and $\beta_n(\alpha)$ do not depend on the shape of the front of the irradiating wave. We shall take the radius of this wave front R_0 as $R_n(\alpha)\approx r_n\sin(\alpha+\varphi_n)+\frac{r_n^2}{R_0}\cos^2(\alpha+\varphi_n)$, here, r_n and ϕ_n are the geometric characteristics of the system of reflectors.

Required here is the determination of the statistical characteristics of the errors of the measurement of the instantaneous values of the quadr ture components and the amplitude of the signal, scattered by the objects indicated when irradiated by a spherical wave, as well as the characteristics of the error in the measurement of the effective scattering surface (EPR) of these objects.

The statistical characteristics of the measurement error of the instantaneous values of the quadrature components of the scattered signal. By using (2), we define the quadrature components of a harmonic signal $z(t) = \mathrm{Re}\{E_{\Sigma}^{0}e^{j\omega t}\}$, scattered by the complex object when irradiated by a spherical wave of radius R_0:

$$\left.\begin{aligned} x^0 &= \sum_{n=1}^{N}\sqrt{\sigma_n(\alpha)}\cos[2kr_n\sin(\alpha+\varphi_n)+2\psi_n\cos^2(\alpha+\varphi_n)+\beta_n(\alpha)],\\ y^0 &= \sum_{n=1}^{N}\sqrt{\sigma_n(\alpha)}\sin[2kr_n\sin(\alpha+\varphi_n)+2\psi_n\cos^2(\alpha+\varphi_n)+\beta_n(\alpha)]\end{aligned}\right\} \tag{3}$$

(here the phase change is $\psi_n = kr_n^2/2R_0$).

By integrating (3) in accordance with (1), it can be shown that for large averaging intervals($-\pi$ -- $+\pi$), the arror in the measurement of the mean values of the quadrature components of the signal, $\langle\Delta x\rangle$ and $\langle\Delta y\rangle$, with an increase in the parameter $2\pi r_n/\lambda$, asymptotically tend to zero (as Bessel functions of the real argument $-J_0(\sqrt{4k^2r_n^2 - d^2})$). When $kr_n > d$, and for the case of spacings between the reflectors commensurate with 2λ (λ is the irradiating wavelength), the mean values of the quadrature components of (3) do not depend on the radius of the irradiating wave front (for the case of a uniform distribution $W(\alpha) - d = 0$).

When the averaging interval decreases down to $\gamma_0 \leq 0.2$ rad, the measurement error in the mean values of the quadrature components increases by approximately an order of magnitude as compared to the error in the entire possible sector of irradiation angles equal to 2π. However, for all systems of reflectors, the spacings between which (in wavelengths) exceed or are commensurate with the quantity which is the inverse of the averaging interval ($r_n \geq \lambda/\gamma_0$), the error considered here is neglectably small.

If we limit ourselves to objects, which are composed of a rather large number of identical reflectors, then where the random quantities $\Delta x_1, \Delta x_2, \ldots, \Delta x_N$ are statistically independent, in accordance with the conditions of the central limiting theorem, the sum $\Delta x = \sum_{n=1}^{N}(x_n^o - x_n^n) = \sum_{n=1}^{N}\Delta x_n$ will be distributed in accordance with a normal law with a mathematical mean value of $\langle\Delta x\rangle = \sum_{n=1}^{N}\langle\Delta x_n\rangle$ and a dispersion of $D\{\Delta x\} = \sum_{n=1}^{N} D\{\Delta x_n\}$. When similar conditions are met for a normal distribution, we also have the sum $\Delta y = \sum_{n=1}^{N}(y_n^0 - y_n^n)$.

It was noted above that in a number of cases of practical importance (and specifically, when $r_n \geq 2\lambda$, $\gamma_0 = \pi$ and $r_n \geq \lambda/\gamma_0$, $\gamma_0 \leq 0.2$ rad), $\langle\Delta x\rangle = \langle\Delta y\rangle = 0$. By using (3), we establish the fact that under the same conditions:

$$\left.\begin{aligned} D\{\Delta x\} = D\{\Delta y\} &\approx \sum_{n=1}^{N}\langle\sigma_n(\alpha)\rangle[1 - J_0(0{,}5\psi_n)\cos\psi_n],\ (-\pi \div +\pi),\\ D\{\Delta x\} = D\{\Delta y\} &\approx 2\sum_{n=1}^{N}\langle\sigma_n(\alpha)\rangle\sin^2\psi_n,\ (\gamma_0 \leqslant 0{,}2 \text{ rad}). \end{aligned}\right\} \quad (4)$$

Consequently, for the case of the random nature of the angle of irradiation of an object, which takes the form of an aggregate of a rather large number of identical reflectors, separated from each other by a distance of several wavelengths, the errors in the measurement of the intstantaneous values of the quadrature components of the signal scattered by this object when irradiated with a spherical wave, are described by a normal distribution with a zero mean value and dispersion, the size of which depends on the radius of the irradiating wave front.

The statistical characteristics of the measurement error of the amplitude of the scattered signal. Since we understand the measurement error to be the difference $\Delta A(\alpha) = A^o(\alpha) - A^n(\alpha)$, then the distribution $W_1(\Delta A)$ is defined by the relationship:

$$W_1(\Delta A) = \int_0^\infty W_2(A^n, A^n + \Delta A)\, dA^n.$$

By employing the well-known procedure for determining the statistical characteristics of a signal amplitude [1], we establish the fact that in the general case, similarly named characteristics of the quadrature components of a signal (3) are different and not equal to zero, the cross-correlation factor between them is not equal to zero and depends on the radius of the irradiating wave front. For this reason, the law governing the distribution of the amplitude of the signal scattered by a complex object, which takes the form of an aggregate of a rather large number of identical reflectors, when irradiated by a spherical wave, corresponds to the generalized probability model of the characteristics of random signals [1]. For practical calculations, it is more convenient to employ an approximation of the actual distribution of the signal amplitude using the Nakagami distribution [2].

By using [1-2], it is not difficult to determine the relationship of the Nakagami distribution parameters m and Δ to the characteristics of the quadrature components [3]. It can be demonstrated that with large spacings between the reflectors (in wavelengths), similarly named parameters of the distribution laws $W(A^0)$ and $W(A^\pi)$ are practically equal to each other ($m^0 \simeq m^\pi = m$, $\Delta^0 \simeq \Delta^\pi = \Delta$). This permits the description of the combined probability density of the amplitudes $W_2(A^0, A^\pi)$ in the form [2]:

$$W_2(A^\pi, A^0, m, \Omega, R_2) = (1 - R_2)^m \sum_{p=0}^{\infty} \frac{(m)_p}{p!} R_2^p W(A^\pi, A^0), \tag{5}$$

where R_2 is the cross-correlation coefficient between the squares of the amplitudes $R\{(A^0)^2, (A^\pi)^2\}$; $(m)_p = m(m+1)\dots(m+p-1)$;

$$W(A^\pi, A^0) = \left\{\frac{2(m+p)^{m+p}}{[\Omega(1-R_2)]^{m+p}\Gamma(m+p)}\right\}^2 (A^0 A^\pi)^{2(m+p)-1} \times$$
$$\times \exp\left\{-(m+p)\frac{(A^0)^2 + (A^\pi)^2}{\Omega(1-R_2)}\right\}.$$

If it is assumed that $\Delta A/A^\pi \leqq 1$, then by employing Mellin's transform [3], we define the explicit form of the law governing the distribution of the error in the measurement of the amplitude of a signal scattered by a complex object when irradiated with a spherical wave:

$$W_1(\Delta A) = (1 - R_2) \sum_{p=0}^{\infty} R_2^p \frac{2^{1-0,5\mu}\sqrt{1+p}}{p!\Gamma(1+p)\Gamma[2(1+p)-0,5]\sqrt{\Omega(1-R_2)}} \times$$
$$\times \exp\left[-\frac{(1+p)\Delta A^2}{\Omega(1-R_2)}\right], \tag{6}$$

$\Gamma(\cdot)$ is a gamma function, $\mu = 4(m + p) - 1$.

When $R_2 \leqq 1$, the series in (6) converges rather quickly. In a first approximation, it is apparent that one can limit oneself to the zero term of this series ($p = 0$). Then by normalizing the area underneath the $W_1(\Delta A)$ curve to unity, we establich the fact that:

$$W_1(\Delta A)=\frac{}{\sqrt{2\pi(1-R_2)\Omega}}\exp\left[-\frac{\Delta A^2}{(1-R_2)\Omega}\right]\left(\text{при } kr_n\geqslant 1,\ \Omega\approx\sum_{n=1}^{N}\langle\sigma_n(\alpha)\rangle\right). \quad (7)$$

Consequently, with large distances between the reflectors, which comprise the complex radar object, the error probability density for the measurement of the amplitude of a signal scattered by this object when irradiated with a spherical wave is described by a normal law with a zero mean value and a dispersion of $D\{\Delta A\}=(1-R_2)\sum_{n=1}^{N}\langle\sigma_n(\alpha)\rangle$.

The cross-correlation coefficient R_2 is nothing other than the cross-correlation coefficient between the effective scattering surface of the object, measured when it is irradiated with a spherical and a plane wave $R\{\sigma^0,\sigma^\pi\}$. Keeping in mind the fact that the effective scattering surface of the object is defined as $\sigma^0 \approx E^0_\Sigma(E^0_\Sigma)^*$ (the * sign signifies the complex conjugate), by using (2), we establish the fact that[1]:

$$R\{\sigma^0,\sigma^\pi\}\approx\frac{\sum\limits_{n<s}\langle\sigma_n(\alpha)\,\sigma_s(\alpha)\rangle\, J_0(0{,}5c_{ns})\cos\psi_{ns}}{\sum\limits_{n<s}\langle\sigma_n(\alpha)\,\sigma_s(\alpha)\rangle},\ (-\pi\div+\pi) \quad (8)$$

$$\left(c_{ns}=\frac{k}{2R_0}\sqrt{r_n^4+r_s^4-2r_n^2r_s^2\cos 2(\varphi_n-\varphi_s)},\ \psi_{ns}=\frac{k(r_n^2-r_s^2)}{2R_0}\right).$$

Arguing in a similar manner, it can be demonstrated that with an increase in the distances between the elementary reflectors, the mean value of the measurement error of the effective scattering surface of the system of these reflectors likewise tends to zero. The dispersion of the measurement error is described in this case by the expression:

$$D\{\Delta\sigma\}\approx 4\sum_{n<s}\langle\sigma_n(\alpha)\rangle\langle\sigma_s(\alpha)\rangle[1-J_0(0{,}5c_{ns})\cos\psi_{ns}]\ (-\pi\div+\pi). \quad (9)$$

If the object consists of reflectors located along the same straight line, $\phi_n = \phi_s$, while the phase change ψ_{ns} does not depend on the subscript n and s and is equal to the phase change in the irradiating wave at the edges of the object, ψ, then we have from (9):

$$D\{\Delta\sigma\}\approx 4[1-J_0(0{,}5\psi)\cos\psi]\sum_{n<s}^{N}\langle\sigma_n(\alpha)\rangle\langle\sigma_s(\alpha)\rangle. \quad (10)$$

---

[1] Expression (8) was derived with the assumption that $\sum\limits_{n=1}^{N}\sum\limits_{s=1}^{N}\langle\sigma_n(\alpha)\,\sigma_s(\alpha)\rangle\approx\left[\sum\limits_{n=1}^{N}\langle\sigma_n(\alpha)\rangle\right]^2$.

Since we are considering a system of identical reflectors, then when N > 5, the sum in (10) $\left(\sum_{n<s}\langle\sigma_n(\alpha)\rangle\langle\sigma_s(\alpha)\rangle \to \frac{N^2}{2}\langle\sigma\rangle^2\right)$ takes the form of the square of the mean value of the effective scattering surface of the object. By designating the measured mean value of the effective scattering surface of the object as $\bar{\sigma}_{ИЗМ}$, we have:

$$D\{\Delta\sigma\} \approx 2(\bar{\sigma}_{изм})^2[1 - J_0(0{,}5\psi)\cos\psi], \ (-\pi \div +\pi). \qquad (11)$$

In a similar manner, we define the dispersion of the measurement error of the effective scattering area of the object in the interval of irradiation angles $\gamma_0 \leq 0.2$ rad:

$$D\{\Delta\sigma\} \approx 2(\bar{\sigma}_{изм})^2 \sin^2\psi. \qquad (12)$$

Since the law governing the distribution of the effective scattering surface of the object in this case ($\sigma \approx A^2$) can be approximated by a Nakagami m-distribution, it is to be anticipated that the measurement errors in the instantaneous values of the effective scattering surface, just as the errors in the measurement of the amplitude, obey a normal distribution law.

A discussion of the results of experimental investigations. Experimental studies of the radar characteristics of models of real objects with a complex shape were carried out to check the theoretical results, where the objects were irradiated with a spherical wave having a phase change at the edges of $\psi_1 = \pi/4$ and $\psi_2 = \pi/2$. In this case, the amplitude variations at the edges of the models did not exceed 2 dB, while the ratio of the maximum dimensions of the models to the length of the irradiating wavelength was $l_{max}/\lambda \geq 30$.

The results of the experimental investigations confirm the justification of the main conclusions of this paper: the errors in the measurement of the power radar characteristics of a number of complex objects, which are due to the sphericity of the irradiating wave front, for the case of a random nature of the irradiation angle, are described by a distribution close to a normal distribution, and are characterized by a neglectibly small mean value (amounting to 10-15% of the true mean value of the quantity being measured), and by a dispersion, the size of which is given with an accuracy of 1.5--2 dB by the formulas given in the preceding section.

Histograms of the distributions of the measurement error of the effective scattering surface of two types of aircraft are shown as an example in Figures 2a and 2b, for the case of a phase change at the edges of ψ_1 in a range of irradiation angles of $-\pi$ -- $+\pi$. The results of the measurements where the phase change was $\psi = \pi/8$ were taken as the true value of the effective scattering surface in this case. It can be seen from Figure 3, where the integral law governing the distribution of the error in the measurement of the amplitude of the signal scattered by one of the aircraft when irradiated with a phase change of ψ_2 (the solid curve represents the experimental results; the dashed curve, the theoretical ones, and a normal distribution; the averaging interval is $-\pi$ -- $+\pi$), that the law governing the distribution of the errors in the measurement of the power radar characteristics of objects with a complex shape is close to a normal distribution. (A check of the degree of agreement between the theoretical and actual distribution based on a χ^2 criterion [4] yields a value of $p = 0.64$ -- 0.8, and based on the Kolmogorov criterion [4], $P = 0.71$ -- 0.86, which indicates the plausibility of the hypothesis advanced here concerning the normal distribution of the errors. Here p and P are the probabilities that the divergence of the theoretical and actual distribution will be no less than those actually recorded in the series of experiments.) In this case, the mean value of the measurement error of the effective scattering surface is neglectibly small (for one of the aircraft, it amounts to ≈ 22 cm^2, where the true mean value of the effective scattering surface is ≈ 250 cm^2, and for the other is ≈ 2 cm^2, where the true mean value is ≈ 120 cm^2), while its dispersion is given with an accuracy of 1.5 dB by formulas (11). Shown in Figures 2 and 3 are the calculated values of $D\{\cdot\}$ and the experimental values of $D^*\{\cdot\}$ of the measurement error dispersion.

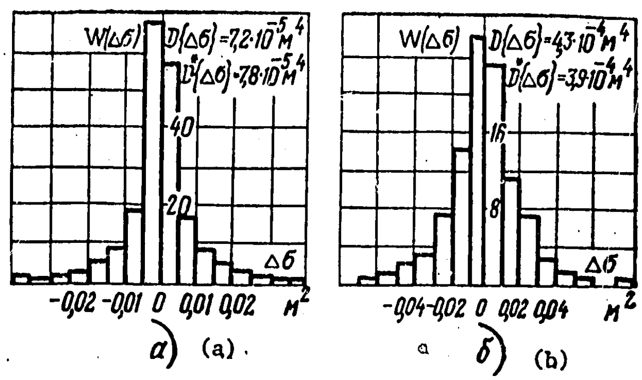


Figure 2.

The theoretical results given above were derived with the following assumptions: 1) There is a sufficiently large number of reflectors which comprise the complex object; 2) The characteristics of the reflector are identical; 3) The reflectors are spaced sufficiently far apart from each other (at a distance of several wavelengths). Conditions 1 and 3 in essense set requirements for the multilobed structure of the secondary radiation pattern, while condition 2 can be interpreted as follows: it is necessary that the maximum value of the effective scattering surface in the specified sector of irradiation angles does not exceed the sum of the effective scattering surfaces measured in all directions in this sector. If in a specified sector N of possible directions (in a cartesion system of coordinates, the number N corresponds to the number of readout points), then condition 2 assumes the following form mathematically:

$$\left(\sum_{i=1}^{N}\sigma_i - \sigma_{max}\right) \Big/ \sigma_{max} \gg 1$$

(just as before, we understand σ to be the effective scattering surface).

The experimental studies made it possible to establish the fact that when $l_{max}/\lambda \geq 30$, and when

$$\frac{\sum_{i=1}^{N}\sigma_i - \sigma_{max}}{\sigma_{max}} > 10$$

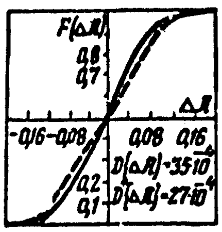


Figure 3.

the law governing the distribution of the errors in the measurement of the power radar characteristics, due to the sphericity of the irradiating wave front, is practically a normal distribution. In large irradiation angle sectors (-π — +π), the second condition is observed for a broad class of real radar objects with a complex shape, and primarily, for aircraft type objects. When the averaging interval is reduced down to $\gamma_0 \leq \pi/3$, formula (11) does not provide for the requisite precision in the determination of the dispersion of the measurement errors. The experiment showed that it is preferable in this case to use (12), which provides for the calculation of the dispersion of the measurement error with a calculation error which does not exceed 2 dB. However, it should be kept in mind that when the averaging interval is reduced, the second condition formulated above is observed only for those sectors in which the influence of the dominant reflector is not felt (for aircraft, such sectors are located in the front and rear hemispheres). However, if the effective scattering surface of an object in a specified sector of irradiation angles is determined entirely by the dominant reflector, then the measurement is also determined by the distortions of the scattering characteristics of this reflector. For this reason, formulas (11) and (12) lose their meaning in this case, and to estimate the measurement error for the effective scattering surface, it is necessary to use other methods (see, for example, [5]). Moreover, it follows from the conditions cited here that the chosen sector cannot be arbitrarily small, since a sufficiently large number of lobes of the secondary radiation pattern should be contained in it. Otherwise, the laws governing the distribution of the erros considered here differ from a normal distribution.

BIBLIOGRAPHY

1. S.I. Pozdnyak, V.A. Melititskiy, "Vvedeniye v statisticheskuyu teoriyu polyarizatsii radiovoln" ["Introduction to the Statistical Theory of Radio Wave Polarization"], Moscow, Sovetskoye Radio Publishers, 1974.

2. M. Nakagami, "The m-Distribution -- A General Formula of Intensity Distribution of Rapid Fadings," "Statistical Methods in Radio Wave Propagation," Pergamon Press, 1960.

3. G. Beytmen, A. Erdeyi, et al., "Tablitsy integral'nykh preobrazovaniy" ["Tables of Integral Transforms"], Vol 1, "Preobrazovaniye Fur'ye, Laplasa, Mellin" ["Fourier, Laplace and Mellin Transforms"], Moscow, Nauka Publishers, 1969.

4. Ye.S. Venttsel', "Teoriya veroyatnostey" ["Probability Theory"], Moscow, GIFML, 1962.

5. Ye.N. Mayzel's, V.A. Torgovanov, "Izmereniye kharakteristik rasseyaniya radiolokatsionnykh tseley" ["Measuring the Scattering Characteristics of Radar Targets"], Moscow, Sovetskoye Radio Publishers, 1972.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.396.96

THE ACTION OF INCOHERENT MULTIPLE POINT SIGNALS ON A DIRECTION FINDER WITH CONICAL SCANNING

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 21-26

[Article by V.D. Dobykin, manuscript received 29 March, 1978]

[Text] Signal processing in single channel direction finders using conical scanning, which are widely used in automatic course tracking systems for air and space objects (ASN), is accomplished using the circuit configuration shown in Figure 1, where PRM [3] is the receiver; D [4] is the envelope detector; SF [5] is a selective filter tuned to the antenna scanning frequency ω_{ck}; FD_1 [6] and FD_2 [7] are phase detectors of the control channels.

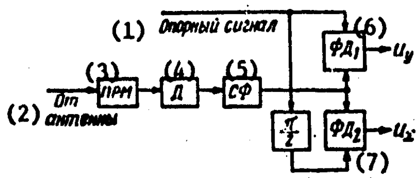


Figure 1.

Key: 1. Reference signal;
2. From the antenna;
3. PRM [receiver];
4. D [detector];
5. SF [selective filter];
6. FD_1 [phase detector 1];
7. FD_2 [phase detector 2].

The problem consists in determining the angular position of the antenna of the direction finder when incoherent signals act on it from n points in space, which fall within the limits of the main lobe of the antenna directional pattern (DNA). For this, we shall find the voltages u_y and u_x at the output of the direction finder.

The resulting signal u(t) at the output of the receiver, PRM, has the form:

$$u(t)=\sum_{j=1}^{n}\xi_j(t)F(\theta_{mj},t), \quad (1)$$

where $\xi_j(t)$ is the signal at the receiver output which comes from the j-th point in space; $F(\theta_{mj}, t)$ is the modulating function, produced by the rotation of the antenna directional pattern; θ_{mj} is the angle which characterizes the spatial position of the antenna directional pattern and which changes at an angular frequency of ω_{ck}.

Inertial AGC, which normalizes the average power of the input signal, is employed in conical scanning direction finders. For this reason, the voltage

(1), strictly speaking, must be multiplied by the variable gain. However, taking this factor into account will have no effect on the final result, since it is assumed that the powers of the signal acting on the direction finder are constant.

If all n signal sources fall within the limits of the main lobe of the direction finder antenna directional pattern, then (1) can be approximated by the following expression with a precision on the order of 50% [1]:

$$u(t)=\sum_{j=1}^{n}\xi_j(t)[1+m_j\cos(\omega_{ck}t+\varphi_j)], \tag{2}$$

where m_j are the amplitude modulation coefficients, where this modulation is formed by the scanning of the direction finder receiving antenna; ϕ_j are the initial phases of the modulated signals, which are determined by the direction of the deviation of the j-th signal source from the equal signal direction (RSN).

With the accuracy indicated above:

$$m_j=K_m\theta_j, \tag{3}$$

where θ_j is the angle between the RSN and the direction to the j-th source; K_m is the slope of the modulation characteristic (the direction finding sensitivity of the antenna) when taking a bearing on a single target. The error in approximating (1) with expression (2) is determined by the precision with which the main section of the direction finding characteristic can be represented in the form of a straight line segment.

Actually, both reflected and the radiated signals in radar are narrow-band random processes, while the case of greatest interest is that where all n signals cannot be differentiated with respect to any of their parameters.

We shall segregate the square of the envelope from signal (2), which with a certain proportionality factor reproduces the voltage at the output of square-law envelope detector D, and consider the fact that only those voltage components pass through the selective filter which are grouped around the scanning frequency. Then the voltage at the output of the selective filter can be written as:

$$u_{SF}(t) = u_{C\Phi}(t)=K_n\sum_{j,l=1}^{n}A_jA_l[m_j\cos(\omega_{ck}t+\varphi_j)+m_l\cos(\omega_{ck}t+\varphi_l)]\cos(\psi_j-\psi_l) \tag{4}$$

where A_j and ψ_j are the envelope and phase of the j-th signal; K_π is the transmission factor of the detector and the selective filter.

Assuming that the phase detector, which have the same transmission factors K_{FD}, perform the operation of multiplying the voltage $u_{SF}(t)$ by the reference voltages $U_0 \cos \omega_{ck}t$ and $U_0 \sin \omega_{ck}t$ (for simplicity in the mathematical derivations, we assume the initial phase of the reference voltages to be equal to zero) as well as that of averaging the resulting products, we find the voltage of the controlling signal - the error signals - in the two direction finding planes:

$$u_y = K_n K_{\text{фд}} \sum_{j,\,l=1}^{n} \langle A_j A_l (m_j \cos\varphi_j + m_l \cos\varphi_l) \cos(\psi_j - \psi_l) \rangle. \tag{5}$$

[$K_{\text{фд}} = K_{FD} = K$, phase detector]

Here, the corner brackets indicate the statistical averaging operation.

The voltage u_x will differ from (5) only by the sines of the initial phases ϕ_j, $j = 1, 2, \ldots, n$.

If we designate $\psi_j - \psi_{j+1} = \Delta\psi_j$, then it can be proved [2] that the unidimensional probability density is:

$$W(\Delta\psi_j) = \begin{cases} (2\pi + \Delta\psi_j)/4\pi^2 & -2\pi \leqslant \Delta\psi_j < 0, \\ (2\pi - \Delta\psi_j)/4\pi^2 & 0 \leqslant \Delta\psi_j < 2\pi, \\ 0 & \text{при других (for other) } \Delta\psi_j \end{cases}$$

и, следовательно,
and, consequently,

$$\langle \cos\Delta\psi_j \rangle = 0, \quad \langle A_j^2 \rangle = 2\sigma_j^2, \tag{6}$$

where σ_j^2 is the dispersion (power) of the j-th signal source.

Taking (6) and (3) into account, the controlling voltages at the output of the direction finder assume the form:

$$\left. \begin{aligned} u_y &= K(\sigma_1^2\theta_{1c} + \sigma_2^2\theta_{2c} + \ldots + \sigma_n^2\theta_{nc}), \\ u_x &= K(\sigma_1^2\theta_{1s} + \sigma_2^2\theta_{2s} + \ldots + \sigma_n^2\theta_{ns}), \end{aligned} \right\} \tag{7}$$

where $K = K_n K_{\text{фд}} K_m, \quad \theta_{jc} = \theta_j \cos\varphi_j, \quad \theta_{js} = \theta_j \sin\varphi_j, \quad j = 1, 2, \ldots, n.$

The ASN system, just as any tracking system, functions in such a manner as to provide that:

$$u_y = 0 \text{ and } u_x = 0 \tag{8}$$

We shall now turn to the spatial position of the signal sources. For this, it is necessary to determine the scattering plane, the orientation of which in space depends on the nature of the physical problem being solved [3]. We shall consider the scattering plane to be the plane XOY, passing through the signal source closest to the direction finder and perpendicular to a line which joins the phase center of the direction finder antenna to the "center of gravity" of a figure formed by the points of intersection of the plane with straight lines running through the signal sources and the phase center of the antenna (points 1, 2, ..., (j - 1), j, ..., (n - 1), n in Figure 2).

The mutual position of the sources for the case of fixed range between them and the direction finder is known and is specified by the matrix of angular distances between the sources:

$$\theta_\Delta = \begin{Vmatrix} \theta_{11}\theta_{12}\ldots\theta_{1n} \\ \theta_{21}\theta_{22}\ldots\theta_{2n} \\ \cdots\cdots \\ \theta_{n1}\theta_{n2}\ldots\theta_{nn} \end{Vmatrix} = \|\theta_{ji}\|,$$

where θ_{ji} is the angle between the j-th and the i-th sources. For small angles θ_{ji}:

$$\theta_{ji}^2 = \theta_{jic}^2 + \theta_{jis}^2, \tag{9}$$

where θ_{jic} and θ_{jis} are the quadrature components of the angles θ_{ji} in the OY and OX planes respectively, which form the matrices $\theta_{\Delta c}$ and $\theta_{\Delta s}$, similar to the matrix θ_Δ. The matrices θ_Δ, $\theta_{\Delta c}$ and $\theta_{\Delta s}$ are skew symmetric to the null diagonal elements, i.e., $\theta_{ji(c,s)} = -\theta_{ij(c,s)}$ and $\theta_{jj(c,s)} = 0$.

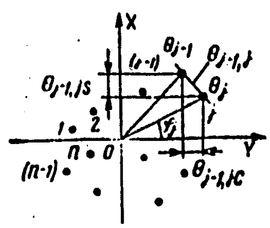


Figure 2.

For the case of unchanged angles between the signal sources, the values of the quadrature components can differ depending on the orientation of the direction finding planes. The degree of approximation of equation (9) is determined by the precision with which the tangents of the angles can be replaced by the angles themselves.

In Figure 2, the segments $\theta_{j-1,j}$, $\theta_{j-1,jc}$ and $\theta_{j-1,js}$ conditionally depict the sides of triangles, the opposite angles of which are equal to $\theta_{j-1,j}$, $\theta_{j-1,jc}$ and $\theta_{j-1,js}$, while the segments which join the origin of the coordinates and the points (j - 1) and j , are formed by the intersection points of the equal signal and the direction to the (j - 1) and j-th sources with the scattering plane. It is not difficult to see from Figure 2 that:

$$\theta_{1c} - \theta_{2c} = \theta_{12c},\ \theta_{2c} - \theta_{3c} = \theta_{23c}, \ldots,\ \theta_{(n-1)c} - \theta_{nc} = \theta_{n-1,nc} \tag{10}$$

comprise (n - 1) independent equation in one direction finding plane, while

$$\theta_{1s} - \theta_{2s} = \theta_{12s},\ \theta_{2s} - \theta_{3s} = \theta_{23s}, \ldots,\ \theta_{(n-1)s} - \theta_{ns} = \theta_{n-1,ns} \tag{10a}$$

are (n - 1) independent equations in the other plane.

By solving (8) and (10), we obtain:

$$\theta_c = \frac{1}{\sum\limits_{j=1}^{n} s_j^2}\theta_{\Delta c}S, \tag{11}$$

where

$$\theta_c = \begin{Vmatrix} \theta_{1c} \\ \theta_{2c} \\ \vdots \\ \theta_{nc} \end{Vmatrix}, \quad S = \begin{Vmatrix} \sigma_1^2 \\ \sigma_2^2 \\ \vdots \\ \sigma_n^2 \end{Vmatrix}$$

Solving (8) and (10a), we obtain an equation for $\theta_s = \begin{Vmatrix} \theta_{1s} \\ \theta_{2s} \\ \vdots \\ \theta_{ns} \end{Vmatrix}$, similar to (11).

The spatial position of the direction finder antenna is determined by the matrix of angles being sought $\theta = \begin{Vmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_n \end{Vmatrix}$, , which found from the expression

$$\theta = \frac{1}{\sum_{j=1}^{n} \sigma_j^2} [\theta_{cg}\theta_c + \theta_{sg}\theta_s]^{1/2}, \tag{12}$$

where θ_{cg} and θ_{sg} are diagonal matrices composed of elements of the matrices θ_c and θ_s respectively.

The j-th element of matrix (12), i.e., the angle between the RSN and the direction to the j-th source in the steady-state mode does not depend on the orientation of the direction finding planes (the OX and OY axes), and is equal to:

$$\theta_j = \frac{[\sigma_1^4\theta_{j1}^2 + \ldots + \sigma_{j-1}^4\theta_{j,j-1}^2 + \sigma_{j+1}^4\theta_{j,j+1}^2 + \ldots + \sigma_n^4\theta_{jn}^2 +}{\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2} \to$$

$$\to \frac{+ \sigma_1^2\sigma_2^2(\theta_{j1}^2 + \theta_{j2}^2 - \theta_{12}^2) + \ldots + \sigma_1^2\sigma_n^2(\theta_{j1}^2 + \theta_{jn}^2 - \theta_{1n}^2) + \ldots +}{} \to$$

$$\to \frac{+ \sigma_{n-1}^2\sigma_n^2(\theta_{j,n-1}^2 + \theta_{jn}^2 - \theta_{n-1,n}^2)]^{1/2}}{}.$$

An analysis of the expressions for θ_j ($j = 1, 2, \ldots, n$) shows that when incoherent signals from n points in space act on the direction finder, the RSN will always fall within the spatial angle enclosing all of the signal sources.

We shall apply the results obtained to specific problems.

1. Let n = 2. Then:

$$\theta_1 = \sigma_2^2\theta_{12}/(\sigma_1^2 + \sigma_2^2), \; \theta_2 = \sigma_1^2\theta_{12}/(\sigma_1^2 + \sigma_2^2) = -\sigma_1^2\theta_{21}/(\sigma_1^2 + \sigma_2^2). \tag{13}$$

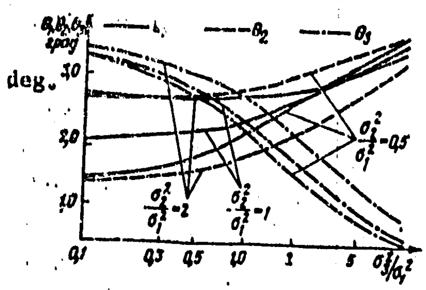


Figure 3.

This result for two-point incoherent interference is widely known [1, 4]. Attention should be drown to the fact that the phase balance condition for signals from two points in space follows from (13).

2. n = 3. The angles θ_1, θ_2, θ_3 as a function of the ratio of the power σ_3^2/σ_1^2 for that orientation of the signal sources of in space where they form an equilateral triangle in scattering plane, and $\theta_{12} = \theta_{23} = \theta_{31} = 4°$.

If the powers of all signals are equal, then $\theta_1 = \theta_2 = \theta_3 = \theta_{12}/\sqrt{3}$. i.e., the gravity of the equilateral triangle.

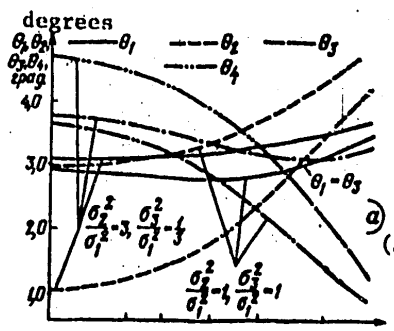


Figure 4a.

3. Let n = 4, The angles θ_1, θ_2, θ_3 and θ_4 are shown in Figures 4a, bb and as functions of the ratio of the powers σ_4^2/σ_1^2 for five fixed values of σ_2^2/σ_1^2 and σ_3^2/σ_1^2 for that orientation of the signal sources in space, where they form a square in the scattering plane and $\theta_{12} = \theta_{23} = \theta_{34} = \theta_{41} = 4°$. If the powers of all the signal are equal, then $\theta_1 = \theta_2 = \theta_3 = \theta_4 =$

(for small angles), i.e., the RSN passes through the center of gravity of the square.

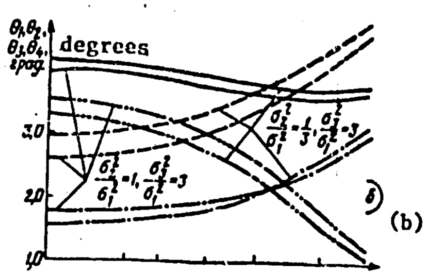


Figure 4b.

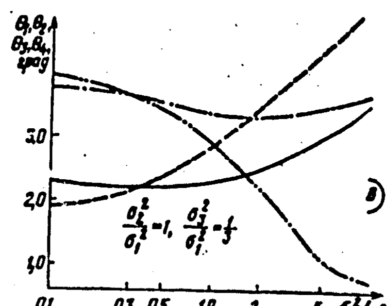


Figure 4c.

BIBLIOGRAPHY

1. S.A. Vakin, L.N. Shustov, "Osnovy radioprotivodeystviya i radiotekhnicheskoy razvedki" ["The Principles of Electronic Countermeasures and Electronic Intelligence"], Moscow, Sovetskoye Radio Publishers, 1968.

2. V.Y. Goryainov, A.G. Zhuravlev, V.I. Tikhonov, "Primery i zadachi po statisticheskoy radiotekhnike" ["Examples and Problems in Statistical Radio Engineering"], Moscow, Sovetskoye Radio Publishers, 1970.

3. L.S. Gutkin, Yu.P. Borisov, et al., "Radiouprableniye reaktivnymi snaryadami i kosmicheskimi apparatami" ["Radio Control of Guided Missiles and Space Vehicles"], Moscow, Sovetskoye Radio Publishers, 1968.

4. "Zashchita ot radiopomekh" ["Protecting Against Radio Interference"], Edited by M.V. Maksimov, Moscow, Sovetskoye Radio Publishers, 1976.

5. Yu.A. Yevsikov, V.V. Chapurskiy, "Preobrazovaniye sluchaynykh protsessov v radiotekhnicheskikh ustroystvakh" ["The Conversion of Random Processes in Radioelectronic Devices"], Moscow, Vysshaya shkola Publishers, 1977.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.3.032.25

AN ELLIPSOIDAL ELECTROMAGNETIC SHIELD

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 53-57

[Article by L.A. Tseytlin]

[Text]. 1. In the theoretical analysis and design of magnetostatic and electromagnetic shields, they are usually replaced by simplified design configurations which are close in terms of shape and dimensions. The basic criteria which determine the selection of the design configuration (besides the correspondence of shape and size), in this case are the permissibility and sufficient simplicity of those boundary magnetostatic electromagnetic problems, to the solution of which the study being conducted leads.

If two or three of the main parameters of the shield are close to each other, then the design configuration can be a thin walled jacket, which has the shape of an oblate or prolate spheroid. The corresponding problems have rather simple solutions both for a magnetostatic shield, and for an electromagnetic shield of a nonmagnetic material (for example, [1 - 4]).

If all three dimensions of the shield differ substantially, then as a first approximation, the shield can be replaced by a thin walled jacket, having the shape of an ellipsoid with three axes. The magnetostatic problem likewise been solved [1]. The similar problem for an electromagnetic shield, as far as we know, has not been analyzed. Its solution is given below.

2. We shall condider a thin ellipsoidal shell with semi-axes a, b and c ($a > b > c$), referenced to a cartesian system of coordinates with the origin in the center of the ellipsoid (Figure 1). We shall consider the shell to be nonmagnetic ($\mu = \mu_0$), and its specific surface conductivity σ, i.e., the product of the volumetric specific conductivity γ times the thickness Δ, when $\Delta \to 0$ and $\gamma \to \infty$, is a finite quantity, and generally speaking, depends on the position of the point on the surface of ellipsoid. We shall pose our own problem of determining the reaction of the shell to the action of an external homogeneous magnetic field H_0, which varies sinusoidally in time at an angular frequency ω. This problem obviously reduces to the solution of Laplace's equation for the scalar potential of a magnetic field, where boundary

conditions should be observed at the surface of the shell, which in the general case of a shell which coincides with the coordinate surface $w = w_0$ of an orthogonal curvilinear system of coordinates u, v, and w, have the form:

$$\frac{\partial \dot{\psi}}{\partial w} = 0, \tag{1}$$

$$\frac{\partial}{\partial u}\left[\frac{\sigma_0}{\sigma}\frac{h_v}{h_u}\frac{\partial \dot{\psi}}{\partial u}\right] + \frac{\partial}{\partial v}\left[\frac{\sigma_0}{\sigma}\frac{h_u}{h_v}\frac{\partial \dot{\psi}}{\partial v}\right] = -i\omega\mu_0\sigma_0\frac{h_u h_v}{h_w}\frac{\partial \dot{\psi}_I}{\partial w}, \tag{2}$$

where $\dot{\psi} = \dot{\psi}_{II} - \dot{\psi}_I$; $\dot{\psi}_I$ and $\dot{\psi}_{II}$ are the scalar potentials of the overall field inside and outside the shell; h_u, h_v and h_w are Lamé coefficients for the coordinates u, v and w; σ_0 is a certain fixed value of the specific surface conductivity σ[5]. It can be seen from (2) that the boundary conditions, and along with them also the entire solution of the problem as a whole depend substantially on the law governing the change in the conductivity σ with respect to the surface of the shell considered here. The solution proves to be the simplest if we assume:

$$\sigma/\sigma_0 = q/h_w, \tag{3}$$

where q is a certain constant which has the same dimensions as the Lamé coefficient h_w*. In this case, on the left side of (2) we have:

$$\frac{1}{q}\frac{\partial}{\partial u}\left(\frac{h_v h_w}{h_u}\frac{\partial \dot{\psi}}{\partial u}\right) + \frac{1}{q}\frac{\partial}{\partial v}\left(\frac{h_u h_w}{h_v}\frac{\partial \dot{\psi}}{\partial v}\right),$$

and since the function $\dot{\psi}$ satifies Laplace's equation:

$$\frac{\partial}{\partial u}\left(\frac{h_v h_w}{h_u}\frac{\partial \dot{\psi}}{\partial u}\right) + \frac{\partial}{\partial v}\left(\frac{h_w h_u}{h_v}\frac{\partial \dot{\psi}}{\partial v}\right) + \frac{\partial}{\partial w}\left(\frac{h_u h_v}{h_w}\frac{\partial \dot{\psi}}{\partial w}\right) = 0$$

and condition (1), then the second boundary condition assumes the form:

$$\frac{\partial^2 \dot{\psi}}{\partial w^2} = i\omega\mu_0\sigma_0 q\frac{\partial \dot{\psi}_I}{\partial w}. \tag{4}$$

Assuming $\dot{\psi}_I = \dot{\psi}_1 + \dot{\psi}_0$, $\dot{\psi}_{II} = \dot{\psi}_2 + \dot{\psi}_0$, where $\dot{\psi}_0$ is the potential of the external field H_0, which acts on the shell, while $\dot{\psi}_1$ and $\dot{\psi}_2$ are the potentials of the shell field in the internal and exterior regions, and taking the continuity of the potential $\dot{\psi}_0$ and its derivative $\partial\dot{\psi}_0/\partial w$ into account at the surface $w = w_0$, instead of the difference $\dot{\psi}_{II} - \dot{\psi}_I$, one can write $\dot{\psi}_2 - \dot{\psi}_1$.

---

* The same simplification is achieved in similar magnetostatic problems when the shell thickness changes in accordance with $\Delta/\Delta_0 = h_w/q$; in particular, for an ellipsoidal shell, this condition is equivalent to the requirement of confocality of the outer and inner surfaces of the shell.

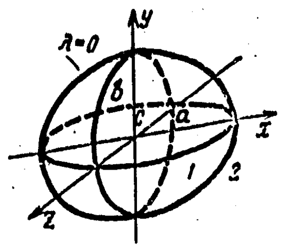


Figure 1.

In the case of an ellipsoidal shield of interest to us here, it natural to employ ellipsoidal coordinates γ, μ, and ν ($\gamma > -c^2 > \mu > -b^2 >$ $> \nu > -a^2$), which are related to the cartesian coordinates x, y and z by the expressions:

$$x^2 = \frac{(a^2+\lambda)(a^2+\mu)(a^2+\nu)}{(a^2-b^2)(a^2-c^2)};$$

$$y^2 = \frac{(b^2+\lambda)(b^2+\mu)(b^2+\nu)}{(b^2-c^2)(b^2-a^2)}$$

$$z^2 = \frac{(c^2+\lambda)(c^2+\mu)(c^2+\nu)}{(c^2-a^2)(c^2-b^2)}. \tag{5}$$

As is well known, the λ, μ, and ν system of coordinates is orthogonal and serving as surface coordinates in it are the confocal ellipsoids λ = const., the hyperboloids of one sheet μ = const., and the hyperboloids of two sheets ν = const., where an ellipsoid with semi-axes of a, b and c correspond to the value $\lambda = 0$ [6]. Since the Lamé coefficients for the cordinates λ, μ, and ν are expressed by the formulas:

$$\left.\begin{aligned} &h_\lambda = \frac{\sqrt{(\lambda-\mu)(\lambda-\nu)}}{2R_\lambda}, \quad h_\mu = \frac{\sqrt{(\mu-\nu)(\mu-\lambda)}}{2R_\mu}, \quad h_\nu = \frac{\sqrt{(\nu-\lambda)(\nu-\mu)}}{2R_\nu}; \\ &R_s = \sqrt{(a^2+s)(b^2+s)(c^2+s)}, \qquad s = \lambda, \mu, \nu, \end{aligned}\right\} \tag{6}$$

then for the surface conductivity σ, we have instead of (3):

$$\sigma = q\sigma_0 \frac{2R_\lambda}{\sqrt{\mu\nu}} = \frac{2q\sigma_0 abc}{\sqrt{\mu\nu}}. \tag{7}$$

The conductivity σ achieves the greatest value ($2q\sigma_0 a$) when μ) when $\mu = -c^2$, $\nu = -b^2$ ($x = \pm a$, $y = z = 0$), and the least value ($2q\sigma_0 c$) when $\mu = -b^2$, $\nu = -a^2$ ($x = y = 0$, $z = \pm c$).

3. Laplace's equation, which is satisfied by the potential ψ_0 of the external field and the potentials ψ_1 and ψ_2 of the shell of the field in the internal and external regions, has the following form in ellipsoidal coordinates:

$$(\mu-\nu) R_\lambda \frac{\partial}{\partial\lambda}\left(R_\lambda \frac{\partial\psi}{\partial\lambda}\right) + (\nu-\lambda) R_\mu \frac{\partial}{\partial\mu}\left(R_\mu \frac{\partial\psi}{\partial\mu}\right) +$$
$$+ (\lambda-\mu) R_\nu \frac{\partial}{\partial\nu}\left(R_\nu \frac{\partial\psi}{\partial\nu}\right) = 0.$$

If its solution is sought using the method of the separationoof variables, i.e., in the form of the sum of the products $\Lambda(\lambda)M(\mu)N(\nu)$, then three equations of the same type are obtained for $\Lambda(\lambda)M(\mu)$ and $N(\nu)$ of the form:

$$\frac{d^2S}{ds^2} + \frac{1}{2}\left(\frac{1}{s+a^2} + \frac{1}{s+b^2} + \frac{1}{s+c^2}\right)\frac{\partial S}{\partial s} = \frac{n(n+1)s+K}{4R_s^2}S, \tag{8}$$

where $S = \Lambda$, M and N; $s = \lambda$, μ and ν; n is a positive integer; and K is a constant. From the various solutions of this equation, called Lamé functions, we require only the functions of the degree $n = 1$, and specifically, functions of the first kind:

$$E_{11}(s) = \sqrt{s+a^2}; \quad E_{12}(s) = \sqrt{s+b^2}; \quad E_{13}(s) = \sqrt{s+c^2} \tag{9}$$

and the functions of the second kind corresponding to them:

$$F_{1m}(s) = \frac{3}{2}E_{1m}(s)\int_s^\infty \frac{ds}{E_{1m}^2(s)R_s} \quad (m = 1, 2, 3), \tag{10}$$

which together with $E_{1m}(s)$ form a system of linear independent solutions of equation (8) when $n = 1$.

When carrying out the calculations using the formulas given below, it is extremely important that the functions F_{1m} can be expressed in terms of the well tabulated elliptical integrals of the first and second kind. In particular, when $s = \lambda$, we have:

$$F_{11}(\lambda) = \frac{3\sqrt{\lambda+a^2}}{(a^2-b^2)\sqrt{a^2-c^2}}[F(\varphi,k) - E(\varphi,k)];$$

$$F_{12}(\lambda) = 3\sqrt{\lambda+b^2}\left\{\frac{\sqrt{a^2-c^2}}{a^2-b^2}\left[\frac{E(\varphi,k)}{b^2-c^2} - \frac{F(\varphi,k)}{a^2-c^2}\right] - \frac{\lambda+c^2}{(b^2-c^2)R_\lambda}\right\};$$

$$F_{13}(\lambda) = \frac{3\sqrt{\lambda+c^2}}{b^2-c^2}\left[\frac{\lambda+b^2}{R_\lambda} - \frac{E(\varphi,k)}{\sqrt{a^2-c^2}}\right],$$

where the modulus k and the argument ϕ are defined by the formula:

$$k^2 = (a^2-b^2)/(a^2-c^2); \quad \sin\varphi = \sqrt{(a^2-c^2)/(\lambda+a^2)}.$$

The derivatives of $F_{1m}(s)$ with respect to s can be found by differentiating the main expression (10):

$$F'_{1m}(s) = \frac{dF_{1m}(s)}{ds} = \frac{3}{2E_{1m}(s)}\left[\frac{F_{1m}(s)}{3E_{1m}(s)} - \frac{1}{R_s}\right].$$

In particular, when $s = \lambda$ and $m = 1$:

$$F'_{11}(\lambda) = \frac{3}{2\sqrt{\lambda+a^2}}\left[\frac{F(\varphi,k) - E(\varphi,k)}{(a^2-b^2)\sqrt{a^2-c^2}} - \frac{1}{R_\lambda}\right]. \tag{11}$$

4. The external magnetic field acting on the shell can always be broken down into components parallel to the x, y, and z axes. Since the course

of the solutionsof the problem of interest to us here for all three components is the same, it is sufficient to analyze only one of them; for the sake of definiteness, we shall assume the field is parallel to the x axis. In this case, the potential $\dot{\psi}_0$ of the external field $\dot{H}_{0x}$ can be represented in the form $\dot{\psi}_0 = -\dot{H}_{0x}x$, or, taking (5) and (11) into account, and limiting ourselves to the range $x > 0$, it can be represented in the form:

$$\dot{\psi}_0 = -\dot{H}_{0x}\frac{\sqrt{a^2+\lambda}\sqrt{a^2+\mu}\sqrt{a^2+\nu}}{\sqrt{a^2-b^2}\sqrt{a^2-c^2}} = -CE_{11}(\lambda)E_{11}(\mu)E_{11}(\nu),$$

where $C = \dot{H}_{0x}/\sqrt{a^2-b^2}\sqrt{a^2-c^2}$, , while E_{11} are Lamé functions of the first kind of the arguments indicated here.

By working from this expression for $\dot{\psi}_0$, and taking into account the obvious symmetry of the field with respect to the xy, yz and zx planes, one can seek the solution of Laplace's equation for the potentials $\dot{\psi}_1$ and $\dot{\psi}_2$ where $x > 0$ in the form:

$$\dot{\psi}_1 = AE_{11}(\lambda)E_{11}(\mu)E_{11}(\nu); \quad \dot{\psi}_2 = BF_{11}(\lambda)E_{11}(\mu)E_{11}(\nu),$$

where $F_{11}(\lambda)$ is a Lamé function of the second kind.

By substituting the latter expressions in the boundary conditions (1) and (4), we determine the constants A and B:

$$A = C\frac{i\xi}{1+i\xi}; \quad B = A\frac{E'_{11}(0)}{F'_{11}(0)},$$

$$\xi = -\frac{4}{3}\omega\mu_0\sigma_0 q\frac{a^2b^2c^2}{b^2+c^2}F'_{11}(0), \tag{12}$$

where

while $F'_{11}(0)$ is the derivative of $F_{11}(\lambda)$ with respect to λ when $\lambda = 0$.

The potential and intensity of the total field in the region 1 being shielded consequently have the form:

$$\dot{\psi}_I = \dot{\psi}_1 + \dot{\psi}_0 = (A-C)E_{11}(\lambda)E_{11}(\mu)E_{11}(\nu) = $$
$$= (A-C)\sqrt{(a^2-b^2)(a^2-c^2)}\,x;$$
$$\dot{H}_{Ix} = -\frac{\partial\dot{\psi}_I}{\partial x} = (C-A)\sqrt{(a^2-b^2)(a^2-c^2)}; \quad \dot{H}_{Iy} = \dot{H}_{Iz} = 0.$$

These formulas essentially solve the problem posed here. In the case analyzed here, the magnetic field in region 1 inside the shell is homogeneous* and is

* This is also justified for the case of the action of two other components of the external field; for this reason, one can assert that when σ varies in accordance with law (7), the ellipsoidal shell is a homogeneously shielding one with respect to a homogeneous external field in any direction.

directed along the x axis, i.e., parallel to the external field H_{0x}. The shielding coefficient, which is identical for all points of the region 1, is equal to:

$$\dot{k} = \dot{H}_{1x}/\dot{H}_{0x} = 1/(1 + i\xi), \tag{13}$$

where ξ is defined by (12), while the quantity $F'_{11}(0)$ needed for the calculation can be found from formula (11), which when $\lambda = 0$, assumes the form:

$$F'_{11}(0) = \frac{3}{2a}\left[\frac{F(\varphi, k) - E(\varphi, k)}{(a^2 - b^2)\sqrt{a^2 - c^2}} - \frac{1}{abc}\right],$$

where $\sin\varphi = \sqrt{1 - c^2/a^2}$.

Expression (13) for the shielding coefficient of an ellipsoidal shield has the same form as for spheroidal shields [4]. Moreover, it can be shown that when $b = c$, formula (12) yields a value for ξ which agrees with that derived in the indicated literature for a prolate spheroidal shield with the corresponding direction of the external field.

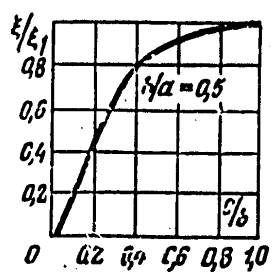


Figure 2.

The influence of the quantity c/b on the shielding coefficient of an ellipsoidal shield is clearly seen in Figure 2, where the coefficient ξ computed from formula (13) is shown as a function of the ratio c/b where the ratio b/a is constant (b/a = 0.5), and for the case of a fixed minimum value of the surface conductivity of the shell σ (the values of the coefficient ξ in this figure are referenced to its value ξ_1 when c/b = 1).

It can be seen from the figure that when c/b is close to unity, the ratio ξ/ξ_1 is likewise close to unity, however, with a considerable difference in the dimensions of b and c, the coefficient ξ for an ellipsoidal shield substantially differs from the corresponding quantity for a spheroidal shield. In such cases, the calculation based on the formulas applying to spheroidal shells can yield a knowingly exaggerated notion of the effectiveness of the shield.

BIBLIOGRAPHY

1. A.G. Greenhill, JOURN. DE PHYS. THEORIQUE ET APPLIQUEE [JOURNAL OF APPLIED AND THEORETICAL PHYSICS], 1881, 10, p 294.

2. H. Kaden, FREQUENZ, 1969, Vol. 32, No. 4.

3. H. Kaden, FREQUENZ, 1969, Vol. 23, NO. 5.

4. S.V. Zhukov, L.A. Tseytlin, RADIOTEKHNIKA, Vol. 26, 1971, No. 8.

5. S.V. Zhukov, ZhTF [JOURNAL OF ENGINEERING PHYSICS], Vol. 39, 1969, No. 7.

6. J.A. Stratton, "Teoriya Elektromagnetizma" ["The Theory of Electromagnetism"], Moscow, Gostekhizdat Publishers, 1948.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.372.8.049.75

AN INVESTIGATION OF L-SHAPED STRIPLINE MATCHING NETWORKS

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 57-62

[Article by A.I. Tolstoy, manuscript received 19 April, 1978]

[Text] Configurations of series connected striplines and stubs are quite frequently used as matching networks in the design of microwave amplifiers [1]. Primarily used in this case are stubs, short-circuited at the high frequency, something which is explained by the necessity of supplying direct current bias to the transistor. The precise design of such stripline structures is difficult due to the complexity of the solution of three-dimensional electrodynamic problems. For this reason, the analysis based on a TEM approximation has become the most widespread [2].

However, a detailed treatment of Γ-shaped stripline matching networks used in transistorized microwave amplifiers is lacking in the literature. These structures are studied below on the basis of the TEM approximation and limits are recommended for the use of this design method, derived on the basis of experiments.

The design of single stage microwave amplifiers using transistors is accomplished by means of analyzing the scattering matrix of the entire stage in terms of the S parameters of the transistors and the parameters of the matching networks [3]:

$$\Gamma_i = (Z_i - Z_0)/(Z_i + Z_0),$$

where Z_i is the input impedance of the input ($i = 1$) or output ($i = 2$) matching network on the transistor side; Z_0 is the characteristic impedance of the microwave channel.

Values of the reflection factors Γ_i are obtained as a result of the calculation, which provide for the requisite amplier parameters. After this, the matching networks are analyzed and synthesized.

The basic schematic of a Γ-shaped stripline matching network is shown in Figure 1. In the general case, the reflection factor $\Gamma = \Gamma_i$ depends on five parameters: the blocking capacitance C_1, needed to provide for direct current decoupling of the amplifier from the external circuit; the lengths l_1 and l_2 and the characteristic resistances ρ_1 and ρ_2 of the striplines (the capacitance of blocking capacitor C_2 is usually large and is not considered in the calculations). Consequently, the analysis of a Γ-shaped stripline matching network can be reduced to the solution of a system of two equations for five unknowns. Such a system of equations either has no solutions or has an infinite number of solutions. For this reason, we shall limit ourselves to the treatment of two possible calculation variants:

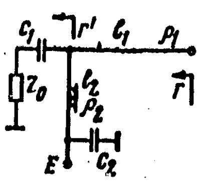


Figure 1.

1. All of the parameters of the matching network are known. It is necessary to determine the reflection factor Γ. For this, we shall make use of the well-known assumptions of [1, 2]:

a) The insertion of a short-circuited stub in the microwave channel equivalent to the connection of a susceptance $y = -i(1/\rho_2)\cot(\beta l_2)$, where $\beta = 2\pi/\lambda'$, $\lambda' = \lambda/\sqrt{\varepsilon'}$; λ is the wavelength in a vacuum; ε' is the effective dielectric permitivity of the substrate on which the matching network is fabricated;

b) The series connection of the stripline into the microwave channel does not change the absolute value of the reflection factor, but changes its phase (if the characteristic impendance of the stripline is equal to the characteristic impedance of the microwave channel):

$$\Gamma = (\Gamma' - a)/(1 - a\Gamma'), \qquad (1)$$

где $|\Gamma'| = |\Gamma''|$;

$$\varphi_1 = \varphi_2 - 2\beta l_1; \qquad (2)$$

$$\Gamma'' = \frac{1 - \bar{\rho}_1 X_c \bar{y} + i(X_c - X_c\bar{\rho}_1 + \bar{y}\bar{\rho}_1)}{1 + \bar{\rho}_1 X_c \bar{y} + i(X_c + X_c\bar{\rho}_1 - \bar{y}\bar{\rho}_1)}; \qquad (3)$$

$X_c = \omega C_1 Z_0$; $\omega = 2\pi f$, f is the frequency for which the matching network is designed; $\bar{\rho}_1 = \rho_1/Z_0$; $\bar{y} = iyZ_0$; $a = (1 - \bar{\rho}_1)/(1 + \bar{\rho}_1)$; φ_1, φ_2 are the phases of Γ' and Γ".

2. The capacitance C_1 and the characteristic impedances of the striplines ρ_1 and ρ_2 are specified. It is necessary to determine the lengths of the striplines l_1 and l_2, which provide for the specified values of Γ. This formulation of the problem is the most real one. Since the size of the capacitance C_1 falls in a discrete range, while ρ_1 and ρ_2 are determined by the width of the striplines, i.e., by the capabilities of the production process, their values are usually specified beforehand.

Taking into account the assumptions made here, it can be shown that the size of the normalized admittance $\bar{y}$ is determined by the formula:

$$\bar{y} = \frac{b}{X_c} \pm \frac{b\bar{\rho}_1 + 1}{\bar{\rho}_1 \sqrt{1-|\Gamma'|^2}} \sqrt{|\Gamma'|^2 - \left(\frac{b\bar{\rho}_1 - 1}{b\bar{\rho}_1 + 1}\right)^2}, \qquad (4)$$

where гле $b = X_c^2/(1 + X_c^2)$; $\Gamma' = (a + \Gamma)/(1 - a\Gamma)$.

An analysis of equation (4) shows that the design of the matching network based on striplines is possible only for specified values of the normalized admittance of the series connectes stripline ρ_1, which satisfy the equation

$$|\Gamma'|^2 \geqslant \left(\frac{b\bar{\rho}_1 - 1}{b\bar{\rho}_1 + 1}\right)^2.$$

The latter inequality can be converted to the form $\bar{\rho}_1^2 bA_1 \geq A_2$, where

$$A_1 = |1 - \Gamma|^2 - b(1 - |\Gamma|^2); \quad A_2 = 1 - |\Gamma|^2 - b|1 + \Gamma|^2.$$

If $A_1 > 0$, then the quantity $\bar{\rho}_1$ is limited with respect to the minimum: $\bar{\rho}_1^2 \geqslant \frac{1}{b}\frac{A_2}{A_1}$. In this case, the design calculation of the matching network always possible $A_2 < 0$.

If $A_1 \leq 0$, the normalized characteristic impedance is limited with respect to the maximum $\bar{\rho}_1^2 \leqslant \frac{1}{b}\frac{A_2}{A_1}$. The calculation of the matching network is impossible if $A_2 > 0$. In this case, it is necessary to increase the capacitance C_1, it can be shown that with a sufficiently large capacitance C_1 ($b \approx 1$), the design calculation of the matching network is always possible if $\rho_1 = 1$.

It is necessary to note that two values of $\bar{y}$ exist, which provide for the requisite reflection factor. If the sign in (4) is taken as plus, then the length of the short-circuited stub is always less than $\lambda'/4$, and if the sign is minus, the length of the stub can be greater than $\lambda'/4$.

After determining $\bar{y}$ from (4), the length of the short-circuited stub is found from the equations:

$$l_1 = \begin{cases} \frac{1}{\beta}\operatorname{arctg}\left(\frac{\rho_1}{\bar{y}Z_0}\right), & \text{if (если) } \bar{y} > 0; \\ \frac{1}{\beta}\left[\pi + \operatorname{arctg}\left(\frac{\rho_1}{\bar{y}Z_0}\right)\right], & \text{if (если) } \bar{y} < 0. \end{cases}$$

The length of the series connected stripline is defined as:

$$l_2 = \begin{cases} \frac{1}{2\beta}(\varphi_2 - \varphi_1), & \text{if (если) } \varphi_2 \geqslant \varphi_1; \\ \frac{1}{2\beta}(2\pi + \varphi_2 - \varphi_1), & \text{if (если) } \varphi_2 < \varphi_1, \end{cases}$$

where ϕ_1 and ϕ_2 are found from (2) and (3).

The width of the stripline and the effective dielectric permittivity of the substrate can be found from the formulas [4]:

$$\rho = \frac{377h}{\sqrt{\varepsilon}\, w \left[1 + 1{,}735\varepsilon^{(-0{,}0724)} \left(\frac{w}{h}\right)^{(-0{,}836)}\right]};$$

$$\varepsilon' = \frac{\varepsilon + 1}{2} + \frac{\varepsilon - 1}{2}\left(1 + 10\frac{h}{w}\right)^{-\frac{1}{2}},$$

where h is the substrate thickness; w is the width of the stripline; ε is the relative dielectric permittivity of the substrate.

The actual topology of a matching network, which is shown in Figure 2, exhibits ambiguity in the finding of the true lengths of the striplines. For example, in determining the length of the series connected stripline l_1, it is necessary to take into account the width of the stub w_2, and when determining the length of the stub, it is necessary to take into account the width of the stripline w_1 and the spacing between the end of the stub and the ground plane. To study the influence of the actual dimensions of the topology on the characteristics of a matching network, test structures were fabricated and studied on substrates made of FAF-4 with a dielectric permittivity of $\varepsilon = 2.5$ and a thickness of $h = 1.5$ mm, as well as substrates made of "Polikor" material with $\varepsilon = 9.8$ and $h = 1$ mm, having combinations of connections of striplines of various widths. The parameters of the matching networks were computed on a digital computer using the procedure given here. The lengths of the striplines were varied with a specific step from $l_1' = l_1$ up to $l_1' = l_1 + w_2$ and from $l_2' = l_2$ up to $l_2' = l_2 + w_1 + \Delta l$.

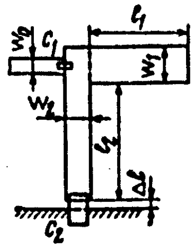


Figure 2.

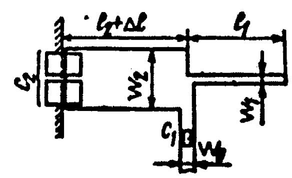


Figure 3.

An analysis of the data obtained allowed for the following conclusions:

1. To increase the precision in the calculation, it is necessary to choose a minimum spacing for Δl.

2. When determining the length of the stub, the thickness of the substrate is to be taken into account (if the ground is made through a hole in the substrate).

3. The width of the type K10-9 capacitors, C_1 and C_2, is chosen equal to the width of the striplines. If the width of a stripline exceeds the width of capacitors C_1 or C_2, then it is expedient to insert several capacitors (as shown in Figure 3), so that the overall width of the capacitors is close to the width of the stripline.

4. If the width of the striplines is approximately the same, then the lengths of the striplines are

$$l'_1 \approx l_1 + w_2/2; \qquad l'_2 \approx l_2 + w_1/2 + \Delta l + h. \tag{5}$$

The results of calculating the characteristics of a stripline matching network, for the corresponding variation in the lengths of the striplines (l_1 = 2.76 cm; l_2 = 3.22 cm; Δl = 0.3 cm; w_1 = 0.38 cm; w_2 = 0.53 cm; $|\Gamma|_{var}$ = 0.45; ϕ_{var} = 36°) are shown in Table 1. The best agreement between the calculated and measured data is for stripline lengths determined from (5) (the corresponding parameters are segregated in Table 1): l'_1 = 3.025 cm; l'_2 = 3.85 cm; $|\Gamma|_{calc}$ = 0.462; ϕ_{calc} = 35.4°.

Table 1

l'_1, см cm	l'_2, см cm	$\lvert\Gamma\rvert$	φ, град degrees
	3,22	0,564	47,0
	3,4	0,533	45,3
2,76	3,584	0,503	43,6
	3,766	0,473	42,0
	3,948	0,444	40,4
	3,22	0,566	41,2
	3,4	0,535	39,5
3,025	3,584	0,506	37,8
	3,766	0,476	36,2
	3,948	0,447	34,7
	3,22	0,569	34,8
	3,4	0,538	33,0
3,29	3,584	0,508	31,4
	3,766	0,479	29,8
	3,948	0,45	28,4

5. For the case of a large difference (of several times) in the width of the striplines, no governing law was found for the determination of the actual lengths of the stripline. This can be explained by the inadequacy of the TEM approximation for the analysis of T-coupling of striplines.

6. An important factor in obtaining agreement between the calculated and experimental characteristics is the ratio of the width and length os the short-circuited stub. It is necessary that its length be greater than the width. The best results were obtained for a stub length equal to no less than twice the width.

An increase in the design calculation quality can be achieved by using the Γ-shaped stripline matching network shown in Figure 3, which permit maintaining the lengths of the striplines more precisely (two capacitors C_2 are needed to improve the high frequency short-circuiting quality). Some two such structures were fabricated on a substrate of of "Polikor" material (l_1 = 1.14 cm; l_2 = 1.05 cm; w_1 = 0.05 cm; w_2 = 0.5 cm; Δl = 0.005 cm; h = 0.1 cm; ρ_1 = 66 ohms; ρ_2 = 17.4 ohms) as well as from FAF-4 material

(l_1 = 4.25 cm; l_2 = 4.4. cm; w_1 = 0.42 cm; w_2 = 2.17 cm; Δl = 0.05 cm; h = 0.15 cm; ρ_1 = 50 ohms; ρ_2 = 13 ohms). The lengths of the striplines were determined sufficiently precisely from the formulas:

$$l_1' = l_1;\; l_2' = l_2 + \Delta l + h.$$

The dimensions of the matching network components were chosen so that resonance characteristics were observed in the range of frequencies studied here. This permits a more careful comparison of the experimental and theoretical characteristics. The parameters of such matching networks (the calculated and experimental values) are shown in Table 2 and Table 3 for the first and second structures respectively. An analysis of the data presented here allows the conclusion that the agreement between the measured and calculated parameters is satisfactory. The study of a number of other similar structures demonstrated that this procedure for the design of the topology of Γ-shaped stripline structures yields an error only in the case where the length of a short-circuited stub is less than its width, or if

Table 2

f, ГГц GHz	(1) Расчет		(2) Измерение		f, ГГц GHz	(1) Расчет		(2) Измерение	
	|Γ|	φ, град. deg.	|Γ|	φ, град. deg.		|Γ|	φ, град. deg.	|Γ|	φ, град. deg.
1,0	0,892	71,4	0,851	75	2,2	0,27	12,7	0,273	13
1,3	0,814	44,8	0,78	45	2,3	0,282	28,9	0,207	25,2
1,5	0,736	28	0,61	30	2,4	0,383	41,3	0,361	47
1,7	0,628	12,5	0,645	15,7	2,6	0,528	35	0,506	29
1,9	0,481	0,07	0,506	1,5	2,8	0,68	21,7	0,643	18,4
2,0	0,397	−3	0,370	−6,5	3,0	0,788	6,8	0,758	3,1
2,1	0,317	0,67	0,285	1					

Key: 1. Design calculation;
2. Measured.

Table 3

f, ГГц GHz	(1) Расчет		(2) Измерение	
	|Γ|	φ, град deg	|Γ|	φ, град deg
0,75	0,698	22,7	0,69	27
1,0	0,165	312	0,151	285
1,25	0,426	56,7	0,41	60,6
1,5	0,803	353,4	0,806	352,8

Key: 1. Design calculation;
2. Measured.

the width of the striplines is comparable to the wavelength corresponding to the working frequency. Consequently, considering these remoarks, the given procedure for the design calculations and the method of structuring matching networks using striplines can be recommended in the design of hybrid integrated microwave assemblies.

BIBLIOGRAPHY

1. V.Kh. Frener, ELEKTRONIKA, 1966, No 18.

2. D.L. Mattey, L. Yang, Ye.M.T. Jons, "Filtry SVCh, soglasuyushchiye tsepi i tsepi svyazi" ["Microwave Filters, Matching Networks and Coupling Circuits"], Vol 1, Translation from the English, Moscow, Svyaz' Publishers, 1971.

3. G.V. Petrov, A.I. Tolstoy, RADIOTEKHNIKA, 1977, Vol 32, No 10.

4. L.G. Maloratskiy, "Mikrominiatyurizatsiya elementov i ustroystv SVCh" ["The Microminiaturization of Microwave Components and Devices"], Moscow, Sovetskoye Radio Publishers, 1976.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.371:537.877

THE INFLUENCE OF THE NONLINEAR PARAMETERS OF A MEDIUM ON THE PROPAGATION AND REFLECTION OF ELECTROMAGNETIC WAVES

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 62-65

[Article by V.I. Vol'man and V.Yu. Vil'davskiy, manuscript received 15 May, 1977]

[Text] When electromagnetic waves propagate in nonlinear media, a frequency conversion takes place - higher harmonic components appear in the general structure of the field, accounting for which is especially important for several reasons.

In the first place, the power of transmitters has increased sharply in recent years. Electromagnetic waves can interact with various objects, having nonlinear properties: the walls of waveguides, the metal structures of antennas, etc. Nonlinear phenomena can also arise when they are reflected from the surface of the earth, as a result of which, spurious radiation outside the band can appear, which makes the solution of the electromagnetic compatibility problem more difficult. With the contemporary strict requirements placed on its level, these sources of radiation outside the band must be taken into account.

In the second place, nonlinear effects open up the prospect of designing fundamentally new radioelectronic devices and procedures. In radar, one can make use of the fact that when a signal is reflected from the surface of nonlinear media, its spectrum is enriched with new harmonic components, and reception is realized at a frequency which is a multiple of the frequency of the radiated signal [1]. This permits utilizing all of the advantages of the CW mode of a radar, and at the same time, avoiding the overloading of the input circuits of its receiver.

Analytical expressions are derived below which describe the structure of the electromagnetic field in a nonlinear medium, and the process of the normal incidence of an electromagnetic wave on the separation boundary of two media, one of which is nonlinear, is analyzed. Relationships are found between the amplitudes and powers of the incident, reflected and refracted waves of different harmonics, something which allowed the performance of numerical calculations on a computer, the results of which are presented in the form of graphs.

The propagation of electromagnetic waves in an infinite nonlinear medium. We shall determine the structure of the electromagnetic field in an infinite medium, the magnetic permiability of which depends on the intensity of the magnetic field H. Let us assume that the conductivity of the medium and its dielectric permittivity are constant, and the functional relationship between the magnetic field vectors is specified:

$$\mathbf{B} = \mu_0 \mu (H) \mathbf{H}, \tag{1}$$

where B is the magnetic induction vector; μ_0 is the magnetic constant; $\mu(H)$ is the relative magnetic permeability which depends on the magnitude of the field.

Expanding $\mu(H)$ in a Maclaurin's series in powers of H, and taking into account the oddness of B as a function of the argument H, we have

$$\mu (H) = \mu_1 + \mu_2 H^2 + \ldots + \mu_{n+1} H^{2n} + \ldots \tag{2}$$

Limiting ourselves to the first two terms of the expansion and substituting (2) in (1), we find

$$\mathbf{B} = \mu_0 \mu_1 \mathbf{H} + \mu_0 \mu_2 H^2 \mathbf{H}. \tag{3}$$

For the case of a plane, homogeneous linearly polarized wave with components E_x and H_y, the system of Maxwell's equation can be reduced to a single scalar differential equation, which taking (3) into account assumes the form

$$\frac{\partial^2 H_y}{\partial z^2} = a_1 \frac{\partial H_y}{\partial t} + a_2 \frac{\varepsilon}{\varepsilon_a} H_y^2 \frac{\partial H_y}{\partial t} + a_3 \frac{\partial^2 H_y}{\partial t^2} + 2a_2 H_y \left(\frac{\partial H_y}{\partial t}\right)^2 + a_2 H_y^2 \frac{\partial^2 H_y}{\partial t^2}, \tag{4}$$

where $\varepsilon_a = \varepsilon_0 \varepsilon$; $a_1 = \sigma \mu_0 \mu_1$; $a_2 = 3\varepsilon_a \mu_0 \mu_2$; $a_3 = \varepsilon_a \mu_0 \mu_1$.

For the solution of (4), we shall employ the method of successive approximations [2], i.e., we shall represent the desired function H_y in the form of an expansion in terms of the parameter a_2:

$$H_y = H_{y0} + H_{y1} a_2 + H_{y2} a_2^2 + \ldots \tag{5}$$

The justification for this approach is determined by the smallness of the parameter a_2 and follows from expression (2), where the product $\mu_2 H^2$ is small as compared to μ_1. We substitute (5) in (4), and group the terms containing identical powers of a_2. By limiting ourselves to the first two equations, we obtain the system of equations:

APPROVED FOR RELEASE: 2007/02/08: CIA-RDP82-00850R000100040023-1

$$\left.\begin{aligned} &\frac{\partial^2 H_{y0}}{\partial z^2} - a_1 \frac{\partial H_{y0}}{\partial t} - a_2 \frac{\partial^2 H_{y0}}{\partial t^2} = 0; \\ &\frac{\partial^2 H_{y1}}{\partial z^2} - a_1 \frac{\partial H_{y1}}{\partial t} - a_2 \frac{\partial^2 H_{y1}}{\partial t^2} = \frac{\sigma}{\varepsilon_a} H_{y0}^2 \frac{\partial H_{y0}}{\partial t} + \\ &+ 2H_{y0}\left(\frac{\partial H_{y0}}{\partial t}\right)^2 + H_{y0}^2 \frac{\partial^2 H_{y0}}{\partial t^2}. \end{aligned}\right\} \tag{6}$$

Solving the system of equations (6) and introducing the complex dielectric permittivity of the medium $\tilde{\varepsilon}_a^{(m)} = \varepsilon_a(1 - i\sigma/m\omega\varepsilon_a)$, (m = 1.3), we derive a general expression for H_y, which describes the magnetic component of the field in a nonlinear medium with a precision good to the third harmonic:

$$\begin{aligned} H_y = C_0 e^{i(\omega t - k^{(11)} z)} + a_2 C_0^3 \left(-\frac{1}{4}\right) \omega^2 |\tilde{\varepsilon}_a^{(1)}| \frac{e^{-i\delta^{(1)}}}{(k^{(11)})^2 - (k^{(13)})^2} e^{i(\omega t - k^{(13)} z)} + \\ + a_2 C_0^3 \left(-\frac{1}{4}\right) 3\omega^2 |\tilde{\varepsilon}_a^{(3)}| \frac{e^{-i\delta(3)}}{(k^{(33)})^2 - (k^{(31)})^2} e^{i(2\omega t - k^{(31)} z)} + C_1 e^{i(3\omega t - k^{(33)} z)}, \end{aligned} \tag{7}$$

where C_0 and C_1 depend on the external source of the amplitude of the magnetic field components; $k^{(11)} = \omega\sqrt{\mu_0\mu_1\tilde{\varepsilon}_a^{(1)}} = \beta - i\alpha$; $k^{(13)} = \beta - i3\alpha$; $k^{(31)} = 3k^{(11)}$; $k^{(33)} = 3\omega\sqrt{\mu_0\mu_1\tilde{\varepsilon}_a^{(3)}}$; $\delta^{(m)}$ is defined from the equation $\tan\delta^{(m)} = \sigma/m\omega\varepsilon_a$ when m = 1.3.

To simplify the writing of the subsequent formulas, we shall represent expression (7) in the form:

$$H_{ym} = C_0 e^{-ik^{(11)} z} + C_0^3 A^{(13)} e^{-ik^{(13)} z} + C_0^3 A^{(31)} e^{-ik^{(31)} z} + C_1 e^{-ik^{(33)} z}. \tag{8}$$

Substituting (7) in the equation $\operatorname{rot} \mathbf{H} = \sigma\mathbf{E} + \varepsilon_a \frac{\partial \mathbf{E}}{\partial t}$, we find the expression for the electrical component of the field:

$$\begin{aligned} E_{xm} = C_0 Z_c^{(11)} e^{-ik^{(11)} z} + C_0^3 A^{(13)} Z_c^{(13)} e^{-ik^{(13)} z} + \\ + C_0^3 A^{(31)} Z_c^{(31)} e^{-ik^{(31)} z} + C_1 Z_c^{(33)} e^{-ik^{(33)} z}, \end{aligned} \tag{9}$$

related to H_{ym} in terms of the characteristic impedances:

$$Z_c^{(mn)} = \frac{k^{(mn)}}{m\omega\tilde{\varepsilon}_a^{(m)}} \quad \text{при} \quad m, n = 1,3. \tag{10}$$

The refraction of electromagnetic waves at the separation boundary with a nonlinear medium. We shall consider the effects which arise when a linearly polarized wave with components E_0 and H_0 is normally incident to the separation boundary of two semi-infinite media (one of which possesses nonlinear properties). It can be treated as a source of field excitation in the nonlinear medium. The quantitative relationships between the amplitudes of the incident, reflected and through traveling waves are of interest here.

We shall introduce a rectangular system of coordinates x, y, and z such that the YOZ plane coincides with the surface of the separation boundary (Figure 1). Then the field of the incident wave is described by the equations:

$$\mathbf{E}_{0m}^{(1)} = \mathbf{y}_0 E_0 e^{-ik_1^{(1)} x}; \quad \mathbf{H}_{0m}^{(1)} = \mathbf{z}_0 H_0 e^{-ik_1^{(1)} x}.$$

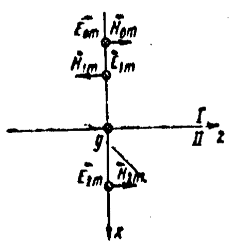


Figure 1.

We shall assume that medium I is linear and has a characteristic impedance of Z_{c1}, while medium II possesses nonlinear properties and its relative magnetic permeability can be represented in the form of (2). We shall introduce the characteristic impedances $Z_{c2}^{(mn)}$ for this medium in accordance with (10). We shall assume that the field of the first harmonic wave traveling through is determined with sufficient precision by components (8) and (9), which have a propagation factor $k_2^{(11)}$. In writing the boundary conditions, we obtain the well-known Fresnel formulas for the reflection factor $R^{(11)} = (Z_{c2}^{(11)} - Z_{c1}^{(1)})/(Z_{c2}^{(11)} + Z_{c1}^{(1)})$ and the transmittance factor $T^{(11)} = 2Z_{c2}^{(11)}/(Z_{c2}^{(11)} + Z_{c1}^{(1)})$ with respect to the first harmonic.

We shall move on to the analysis of the third harmonic fields. Since the amplitude of the incident wave of this harmonic is equal to zero, then the expressions for the fields of only the reflected and through traveling waves participate in the writing of the boundary conditions. By solving the resulting equations, we find the final expression which describe the structure of the complete field in the upper and lower half-spaces:

$$\mathbf{E}_{1m} = \mathbf{y}_0 \left(H_0 R^{(11)} Z_{c1}^{(1)} e^{ik_1^{(1)} x} + H_0^3 A^{(31)} B^3 R^{(33)} Z_{c1}^{(3)} e^{ik_1^{(3)} x} \right);$$

$$\mathbf{H}_{1m} = -\mathbf{z}_0 \left(H_0 R^{(11)} e^{ik_1^{(1)} x} + H_0^3 A^{(31)} B^3 R^{(33)} e^{ik_1^{(3)} x} \right);$$

$$\mathbf{E}_{2m} = \mathbf{y}_0 \Big(H_0 B Z_{c2}^{(11)} e^{-ik_2^{(11)} x} + H_0^3 A^{(13)} B^3 Z_{c2}^{(13)} e^{-ik_2^{(13)} x} + H_0^3 A^{(31)} B^3 Z_{c2}^{(31)} e^{-ik_2^{(31)} x} + H_0^3 A^{(31)} B^3 T^{(33)} Z_{c2}^{(33)} e^{-ik_2^{(33)} x} \Big);$$

$$\mathbf{H}_{2m} = \mathbf{z}_0 \Big(H_0 B e^{-ik_2^{(11)} x} + H_0^3 A^{(13)} B^3 e^{-ik_2^{(13)} x} + H_0^3 A^{(31)} B^3 e^{-ik_2^{(31)} x} + H_0^3 A^{(31)} B^3 T^{(33)} e^{-ik_2^{(33)} x} \Big),$$

where $B = T^{(11)} \dfrac{Z_{c1}^{(1)}}{Z_{c2}^{(11)}}$; $R^{(33)} = \dfrac{Z_{c2}^{(31)} - Z_{c1}^{(33)}}{Z_{c1}^{(3)} + Z_{c2}^{(33)}}$; $T^{(33)} = -\dfrac{Z_{c2}^{(31)} + Z_{c1}^{(3)}}{Z_{c1}^{(3)} + Z_{c2}^{(33)}}$.

The relationships between the powers of the incident wave and the reflected and through traveling waves of the third harmonic are of substantial practical interest, and specifically:

$$Q_1 = P^{(3)}_{avg.ref.}/P^{(1)}_{avg.inc.}; \qquad Q_2 = P^{(3)}_{avg.trav.}/P^{(1)}_{avg.inc.},$$

where $P^{(3)}_{avg.ref.}$ and $P^{(3)}_{avg.trav.}$ are the average values over a period of the Poynting vectors of the reflected and traveling waves of the third harmonic; $P^{(1)}_{avg.inc.}$ is the average value of the Poynting vector of the incident wave, which characterizes the excitation power. It can be shown that $Q_1 = Q_2$.

The calculation of the power flows and the quantities Q_1 and Q_2 was carried out on a computer using a program written in Fortran-IV language. The results of the calculation of the coefficients Q_1 and Q_2 are shown in Figure 2, where: a) $\varepsilon = 1$, $\sigma = 5.67 \cdot 10^7$ mhos/m, and $\mu_2 = 0.1\mu_1$; b) $\varepsilon = 10$, $\sigma = 0.01$ mhos/m, and $\mu_2 = 0.01\mu_1$. Along with a reduction in the amplitude of the exciting wave in step with an increase in λ, the power of the third harmonic excited in the nonlinear medium also falls off.

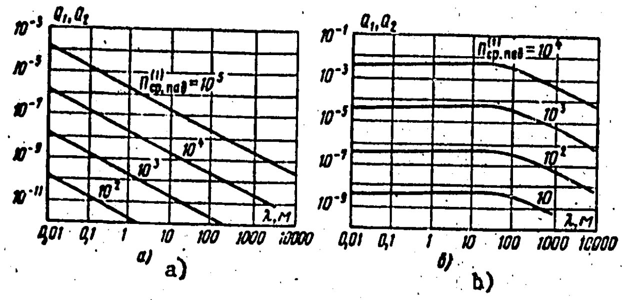


Figure 2.

$$\Pi^{(1)}_{\text{ср.пад}} = P^{(1)}_{avg.inc.}$$

An important result of the numerical calculations was the estimation of nonlinear effects which arise when electromagnetic waves are reflected from the surface of the ground (Figure 2b). The fact that metal structures can be present at the surface of the ground alongside the antennas permits considering the ground as a nonlinear medium. Moreover, the presence of natural feromagnetic inclusions in the earth can become a cause of the appearance of nonlinear effects.

When the power flux of the incident wave is on the order of 100 w/m^2, the relative third harmonic level amounts to -65 dB, in which case an increase in irradiation intensity leads to a square-law increase in the level of the out-of-band radiation, which attains a level of -25 dB at an irradiation power of 10,000 w/m^2 (based on modern requirements, -100 dB -- -80 dB is permitted). As the calculations have shown, this figure is exceeded at irradiation power fluxes as low as on the order of 10 w/m^2.

BIBLIOGRAPHY

1. M.L. Georgi, US Patent No. 3732567 of 8 May, 1973.

2. P.M. Kolesnikov, "Vvedeniye v nelineynuyu elektrodinamiku" ["Introduction to Nonlinear Electrodynamics"], Minsk, Nauka i Tekhnika Publishers, 1971.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.397:535

THE TELEVISION TRANSMISSION OF FRESNEL HOLOGRAMS

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 66-70

[Article by O.V. Gofayzen and A.V. Mindel', manuscript received 24 October, 1977]

[Text] A series of experimental [1 - 5] and theoretical [6 - 7] works have been devoted to an analysis of the transmission of holograms via television. The greatest attention in the theoretical work has been devoted to an analysis of the transmission of Fourier holograms. At the same time, one of the most widely disseminated schemes for holography among the considerable diversity of types is the Fresnel scheme [13, 14]. In this regard, an investigation of the transmission of Fresnel holograms is a pressing problem.

An analysis of the television transmission of Fresnel holograms was carried out in [8, 9], where the distortions of all of the hologram components are studied when transmitted via television channel, as well as the manifestation of these distortions in the reproduced image. It became clear from these works that, as a whole, the frequency-contrast characteristic of the television holographic system has an influence on the reproduced image, however, the specific features of the distortions of the reproduced image, related to the digitization of the hologram in the television transmission process remained inadequately studied. In particular, it remained unclear which distortions in the reproduced image were due to digitization during analysis, transmission via the electrical channel, and synthesis. Since this question is a fundamental one for holographic television, it has been taken as the task of this paper.

We shall limit ourselves to a treatment of the transmission of one information component of a hologram, corresponding to a real image of an object with an amplitude transmission of $t_1(\alpha, \beta)$:

$$s_1(x, y) = a^*(x, y)\exp[i(\omega_1 x + \omega_2 y)],$$

where $a(x, y)$ is the complex amplitude of the object wave in the plane of the hologram; x and y are the coordinates of the plane of the hologram; $\exp[i(\omega_1 x + \omega_2 y)]$ is the complex amplitude of the plane reference wave;

$\omega_1 = 2\pi\sin\theta_1/\lambda$; $\omega_2 = 2\pi\sin\theta_2/\lambda$; θ_1 and θ_2 are the angles formed by the front of the reference wave with the x and y axes; λ is the wavelength of the radiation of the coherent light source.

As a result of the digitization during the analysis, transmission via the communications channel, and synthesis, a television image of the hologram is formed which is a function of the spatial and time coordinates. Of interest for holographic television is the case where the images are reproduced in holograms in step with the arrival of the holographic information. In this case, the synthesized hologram is recorded in real time on an intermediate carrier, from the image of the object is subsequently reproduced. The recording process can be depicted as integration within the limits of each scanning field. In the general case, where there is interlacing with a multiplicity factor K, the hologram image which is recorded on the carrier, upon the completion of the field with the number m_y, is described by the formula [12]:

$$\begin{aligned} s_2(x,y) = \frac{T_x^2 T_y^2}{XY} g_2(x,y) \otimes\otimes \Big\{ P_{\frac{X}{2},\frac{Y}{2}}(x,y) \times \\ \times \sum_{m_x=-\infty} \delta\left[T_x\left(\frac{x}{X} - m_x\right) - T_y\left(\frac{y}{Y} - m_y\right)\right] \times \\ \times \Big[s(x,y) \otimes\otimes \sum_{n_x=-\infty}^{\infty} \sum_{n_y=-\infty}^{\infty} h\left[T_x\left(\frac{x}{X} + n_x\right)\right] \times \\ \times \delta\left[T_x\left(\frac{x}{X} + n_x\right) - T_y\left(\frac{y}{Y} + n_y\right)\right]\Big]\Big\}, \end{aligned} \tag{1}$$

where

$$s(x,y) = XYP_{\frac{X}{2},\frac{Y}{2}}(x,y)[s_1(x,y) \otimes\otimes g_1(x,y)];$$

$$P_{\frac{X}{2},\frac{Y}{2}}(x,y) = \begin{cases} \frac{1}{XY} & \text{при } |x| < \frac{X}{2},\ |y| < \frac{Y}{2}, \\ 0 & \text{при } |x| > \frac{X}{2} \text{ или } |y| > \frac{Y}{2}; \end{cases} \tag{2}$$

X and Y are the horizontal and vertical dimensions of the frame produced during scanning; T_x and T_y are the scanning periods along the horizontal and vertical; h(t) is the pulse response of the electrical channel; $g_1(x,y)$ and $g_2(x,y)$ are the weighting functions of the analyzing and synthesizing elements. The Fourier transform of the function $s_2(x,y)$ has the form:

$$S_2(\omega_x, \omega_y) = \frac{4\pi^2 T_y}{XY} G_2(\omega_x, \omega_y) \sum_{p=-\infty}^{\infty} \sum_{l_x=-\infty}^{\infty} \sum_{l_y=-\infty}^{\infty} S\left(\frac{2\pi}{X} l_x, \frac{2\pi}{Y} l_y\right) \times$$
$$\times H\left(\frac{2\pi}{T_x} l_x + \frac{2\pi}{T_y} l_y\right) \operatorname{sinc}\left[\omega_x + \frac{2\pi}{X}(p - l_x)\right] \frac{X}{2} \times$$
$$\times \operatorname{sinc}\left[\omega_y - \frac{2\pi}{Y}\left(p\frac{T_y}{T_x} + l_y\right)\right] \frac{Y}{2} \exp\left(-i2\pi\, pm_y \frac{T_y}{T_x}\right), \qquad (3)$$

(3)

where

$$\operatorname{sinc} x = \sin x / x;\ S(\omega_x, \omega_y) = \frac{XY}{4\pi^2} [S_1(\omega_x, \omega_y) G_1(\omega_x, \omega_y)] \otimes\otimes \left(\operatorname{sinc}\frac{\omega_x X}{2} \times \right.$$
$$\left. \times \operatorname{sinc}\frac{\omega_y Y}{2}\right)];\ S_1(\omega_x, \omega_y) = a_1 T_1^*(\omega_1 - \omega_x, \omega_2 - \omega_y) \exp\left\{i \frac{\lambda q}{4\pi} [(\omega_x - \omega_1)^2 + \right.$$
$$\left. + (\omega_y - \omega_2)^2]\right\}$$

is the Fourier transform of the information component of the hologram, corresponding to the actual image; a_1 is the amplitude of the plane wave which illuminates the transparency; $T_1(\omega_x, \omega_y)$ is the Fourier transform of the amplitude transmittance function of the transparency; $H(\omega)$ is the transfer function of the television channel; $G_1(\omega_x, \omega_y)$ and $G_2(\omega_x, \omega_y)$ are two-dimensional aperture-frequency characteristics of the analyzing and synthesizing devices.

If in the reproduction stage, the synthesized hologram is illuminated by a plane wave, which has the complex amplitude of $r(x, y) = \exp[-i(\omega_1 x + \omega_2 y)]$ in the plane of the hologram, the complex anplitude of the field immediately following the hologram is expressed by the formula $a_2(x, y) = s_2(x, y) \cdot \exp[-i(\omega_1 x + \omega_2 y)]$.

The Fourier transform of this function is $A_2(\omega_x, \omega_y) = S_2(\omega_x + \omega_1, \omega_y + \omega_2)$.

The spatial frequency spectrum of the complex amplitude of the wave in the plane of the restored image has the form:

$$T_2(\omega_\xi, \omega_\eta) = A_2(\omega_\xi, \omega_\eta) \exp\left[-i\frac{\lambda q}{4\pi}(\omega_\xi^2 + \omega_\eta^2)\right] = S_2(\omega_\xi + \omega_1, \omega_\eta + \omega_2) \times$$
$$\times \exp\left[-i\frac{\lambda q}{4\pi}(\omega_\xi^2 + \omega_\eta^2)\right]. \qquad (4)$$

(4)

The expression for the function $S_2(\omega_x, \omega_y)$ for insertion in formula (4) is rather complex for the subsequent analysis. To simplify this expression, we shall assume that within the limits of the passband of the holographic signal, the frequency response of the channel is smooth and varies insignificantly within the range of any of the frequency intervals with a width of $2\pi/T_y$. Taking this into account, (3) is transformed on the basis of Kotel'nikov's theorum to the following form:

$$S_2(\omega_x, \omega_y) = \frac{4\pi^2 T_y}{XY} G_2(\omega_x, \omega_y) H\left(\frac{X}{T_x}\omega_x + \frac{Y}{T_y}\omega_y\right) \times$$
$$\times \sum_{p=-\infty}^{\infty} S\left(\omega_x + p\frac{\pi 2}{X}, \omega_y - p\frac{2\pi T_y}{YT_x}\right) \exp\left(-i2\pi p m_y \frac{T_y}{T_x}\right).$$

(5)

Only the specific distortions arising as a result of the television transmission of the hologram are studied in this investigation, and for this reason, in the following we shall neglect the distortions of the reproduced image which are related to the limiting of the hologram with respect to size, and make use of a simplified expression for $S(\omega_x, \omega_y)$:

$$S(\omega_x, \omega_y) = S_1(\omega_x, \omega_y) O_1(\omega_x, \omega_y). \tag{6}$$

Substituting (6) and (5), we derive a formula for the Fourier transform of the hologram:

$$\begin{aligned} S_2(\omega_x, \omega_y) = {} & \frac{4\pi^2 T_y a_1}{XY} O_2(\omega_x, \omega_y) H\left(\frac{X}{T_x}\omega_x + \frac{Y}{T_y}\omega_y\right) \times \\ & \times \sum_{p=-\infty}^{\infty} O_1\left(\omega_x + p\frac{2\pi}{X},\ \omega_y - p\frac{2\pi}{Y}\frac{T_y}{T_x}\right) T_1^*\left(\omega_1 - \omega_x - p\frac{2\pi}{X}, \omega_2 - \omega_y + \right. \\ & \left. + p\frac{2\pi}{Y}\frac{T_y}{T_x}\right) \exp\left\{i\frac{\lambda q}{4\pi}\left[\left(\omega_x + p\frac{2\pi}{X} - \omega_1\right)^2 + \right.\right. \\ & \left.\left. + \left(\omega_y - p\frac{2\pi}{Y}\frac{T_y}{T_x} - \omega_2\right)^2\right]\right\} \exp\left(-i2\pi p m_y \frac{T_y}{T_x}\right). \end{aligned}$$

Substituting $S_2(\omega_x, \omega_y)$ in formula (4), which describe the spectrum of the reproduced image, we obtain:

$$\begin{aligned} T_2(\omega_\xi, \omega_\eta) = {} & \frac{4\pi^2 T_y a_1}{XY} O_2(\omega_\xi + \omega_1, \omega_\eta + \omega_2) H\left[\frac{X}{T_x}(\omega_\xi + \omega_1) + \right. \\ & \left. + \frac{Y}{T_y}(\omega_\eta + \omega_2)\right] \sum_{p=-\infty}^{\infty} O_1\left(\omega_\xi + \omega_1 + p\frac{2\pi}{X}, \omega_\eta + \omega_2 - p\frac{2\pi}{Y}\frac{T_y}{T_x}\right) \times \\ & \times T_1^*\left(-\omega_\xi - p\frac{2\pi}{X}, -\omega_\eta + p\frac{2\pi}{Y}\frac{T_y}{T_x}\right) \exp\left\{i\frac{\lambda q}{4\pi}\left[\left(\omega_\xi + p\frac{2\pi}{X}\right)^2 + \right.\right. \\ & \left.\left. + \left(\omega_\eta - p\frac{2\pi}{Y}\frac{T_y}{T_x}\right)^2\right]\right\} \exp\left[-i\frac{\lambda q}{4\pi}(\omega_\xi^2 + \omega_\eta^2)\right] \exp\left(-i2\pi p m_y \frac{T_y}{T_x}\right). \end{aligned}$$

Following the transformation of the exponential cofactors, we arrive at the formula:

$$\begin{aligned} T_2(\omega_\xi, \omega_\eta) = {} & \frac{4\pi^2 T_y a_1}{XY} O_2(\omega_\xi + \omega_1, \omega_\eta + \omega_2) H\left[\frac{X}{T_x}(\omega_\xi + \omega_1) + \frac{Y}{T_y}(\omega_\eta + \omega_2)\right] \times \\ & \times \sum_{p=-\infty}^{\infty} T_1^*\left(-\omega_\xi - p\frac{2\pi}{X}, -\omega_\eta + p\frac{2\pi}{Y}\frac{T_y}{T_x}\right) O_1\left(\omega_\xi + \omega_1 + p\frac{2\pi}{X},\right. \\ & \left. \omega_\eta + \omega_2 - p\frac{2\pi}{Y}\frac{T_y}{T_x}\right) \exp\left[i p\lambda q\left(\frac{\omega_\xi}{X} - \frac{T_y}{T_x}\frac{\omega_\eta}{Y}\right)\right] \times \\ & \times \exp\left[i p^2 \lambda q\left(\frac{\pi}{X^2} + \frac{\pi}{Y^2}\frac{T_y^2}{T_x^2}\right)\right] \exp\left(-i2\pi p m_y \frac{T_y}{T_x}\right). \end{aligned}$$

Since $t(x, y)$ is a real function, we have the expression

$$T_1^*(-\omega_x, -\omega_y) = T_1(\omega_x, \omega_y).$$

Taking this into account, as well as the fact that $T_y/T_x = z/K$ (z is the number of lines in a frame), we finally obtain:

$$T_2(\omega_\xi, \omega_\eta) = \frac{4\pi^2 T_y a_1}{XY} O_2(\omega_\xi + \omega_1, \omega_\eta + \omega_2) H\left[\frac{X}{T_x}(\omega_\xi + \omega_1) + \frac{Y}{T_y}(\omega_\eta + \omega_2) \times\right.$$
$$\times \sum_{p=-\infty}^{\infty} T_1\left(\omega_\xi + p\frac{2\pi}{X}, \omega_\eta - p\frac{2\pi}{Y}\frac{z}{K}\right) O_1\left(\omega_\xi + \omega_1 + p\frac{2\pi}{X}, \omega_\eta +\right.$$
$$\left. + \omega_2 - p\frac{2\pi}{Y}\frac{z}{K}\right) \exp\left[i p\lambda q\left(\frac{\omega_\xi}{X} - \frac{\omega_\eta}{Y}\frac{z}{K}\right)\right] \times$$
$$\times \exp\left[i p^2 \pi\lambda q\left(\frac{1}{X^2} + \frac{z^2}{K^2 Y^2}\right)\right] \exp\left(-i2\pi p m_y \frac{z}{K}\right). \qquad (7)$$

Expression (7) describes the spatial frequency spectrum of the distribution of the amplitudes of the light field in the restored image of the object. In analyzing this expression, one can study the characteristic distortions of the image.

As a result of the digitization of the hologram by lines during restoration, the primary image is produced as well as diffraction orders. The presence of the first exponential cofactor indicates that the orders are spaced $\lambda q/X$ apart along the horizontal and $\lambda qz/KY$ apart along the vertical. In order to avoid superposition of the orders, the vertical size of the object must be chosen based on the condition $\Delta v \leq \lambda qz/KY$.

The parameter K which is included in the denominator of this expression indicates the fact that with an increase in the interlace multiplicity factor, the permissible size of the image decreases, from which it follows that it is most expedient to employ progressive scanning ($K = 1$).

The second exponential cofactor attests to the fact that each of the orders has a certain initial phase, proportional to the square of the number of the order and which depends on the dimensions of the hologram, the number of lines, the interlacing multiplicity factor and the spacing between the object and the hologram.

The third exponential cofactor characterizes the change in the polarity of the amplitude distribution in the plane of the restored image from field to field. For example, when $K = 2$ (conventional interlace scanning), the orders with odd numbers change their polarity from field to field, while those with even numbers retain their polarity in all fields. At the points where the main image overlaps the orders formed between them in alternate fashion are summ and difference fields, something which is perceived as flickering.

The terms $p(2\pi/X)$ and $p(2\pi/Y)(z/K)$ in the expression for the Fourier transform of the object, which enter into (7), indicate the fact that in the light field of the orders of the restored image there is a phase change which is proportional to the numbers of the orders, by virtue of which, the field amplitudes add geometrically at the overlap points of the latter.

The aperture distortions during hologram analysis and synthesis, as well as the distortions during transmission through the electrical channel, lead to distortion of the definition of the restored image. The manifestation of these distortions depends on the slope angle of the reference beam. In this case, a shift arises in the frequency characteristics relative to the spectrum of the spatial frequencies of the object by the amounts ω_1 and ω_2, something which leads to a reduction in the contrast of the restored image and the appearance of distortions in it, which arise due to the unequal transmission of the negative and positive frequencies of the spectrum. The analysis characteristic influences the definition of the primary image and the diffraction orders in an identical manner, while both the frequency characteristics of the channel and the synthesis are additionally shifted with respect to the spectra of the orders by the frequencies $p(2\pi/X)$ and $p(2\pi/Y)(z/K)$. The argument of the frequency characteristic of the channel attests to the fact that it should be broadband, where the position of the center frequency basically depends on the frequency ω_1 which characterizes the angle formed by the reference wave front with the x axis. A more precise idea can be obtained by means of comparing formula (7) to the analytical expression for the signal spectrum obtained earlier [11]. The conclusions given here supplement and specify more precisely the ideas existing in the literature concerning distortions in an image restored from a Fresnel hologram transmitted by television. The results of the paper and the methodology of the investigations can be used to calculate the distortions of the restored image in Fresnel holography and for a wide class of holography procedures used in practice, for example, for the analysis of the transmission of redundant holograms.

BIBLIOGRAPHY

1. L.M. Enloe, J.A. Murphy, C.B. Rubinstein, BSTJ, 1966, Vol 45, No 2.

2. I.S. Klimenko, G.I. Rukman, ZHTF [JOURNAL OF ENGINEERING PHYSICS], 1967, Vol 37, No 8.

3. S.B. Gurevich, G.A. Gavrilov, A.B. Konstantinov, et al., ZHTF, 1968, Vol 38, No 3.

4. P.V. Shmakov, V.G. Zhevel', P.N. Kopylov, et al., TEKHNIKA KINO I TELEVIDENIYA [MOTION PICTURE AND TELEVISION ENGINEERING], 1969, No 10.

5. B.P. Konstantinov, S.B. Gurevich, G.A. Gavrilov, et al., ZHTF, 1969, Vol 39, No 2.

6. O.V. Gofayzen, A.V. Vykhodets, RIR, No 23, 1970, Ref. 22905.

7. O.V. Gofayzen, V.F. Brin'ko, SB. REF. DEP. RUK. RABOT [Unknown Collection], 1973, No 4.

8. V.P. Bordun, D.F. Chernykh, ZHTF, 1973, Vol 43, No 4.

9. D.F. Chernykh, "Materialy 4-y Vsesoyuznoy shkoly po golografii 1972" ["Materials of the 1972 Fourth All-Union School on Holography"], Leningrad, 1973.

10. O.V. Gofayzen, A.V. Mindel', V.F. Brin'ko, RADIOTEKHNIKA, 1976, Vol 31, No 4.

11. O.V. Gofayzen, A.V. Mindel', V.F. Brin'ko, RADIOTEKHNIKA, 1976, Vol 31, No 1.

12. O.V. Gofayzen, A.V. Mindel', "Sb. RIPORT", No 1, 1975, VIMI [Unknown].

13. R. Kol'yer, K. Berkkhart, L. Lin, "Opticheskaya golografiya" ["Optical Holography"], Moscow, Mir Publishers, 1973.

14. S.B. Gurevich, G.A. Gavrilov, D.F. Chernykh, in the collection, "Sovremennoye sostoyaniye i perspektivy razvitiya golografii" ["The State of the Art and the Developmental Prospects for Holography"], Leningrad, Nauka Publishers, 1974.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.316.771.011.73

DESIGNING CHANNELS WITH CONTROLLED RESISTIVE ATTENUATORS FOR A SPECIFIED SHAPE OF THE FREQUENCY RESPONSE

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 71-74

[Article by N.I. Okulich, manuscript received 6 April, 1978]

[Text] In the process of adjusting the transmission factor of an amplifying channel, which contains a controlled attenuator, it is possible to change the shape of its frequency response (ChKh) [1]. It was shown in [2] that constancy of the shape of the frequency response requires that two conditions be met:

$$\bar{a}_m Z_н + \bar{b}_m + \bar{c}_m Z_г Z_н + \bar{d}_m Z_г = 0; \tag{1}$$

$$\frac{\bar{a}}{\bar{a}_m} = \frac{\bar{b}}{\bar{b}_m} = \frac{\bar{c}}{\bar{c}_m} = \frac{\bar{d}}{\bar{d}_m}, \tag{2}$$

where $\bar{a} = a - Sa_0$; $\bar{b} = b - Sb_0$, $\bar{c} = c - Sc_0$; $\bar{d} = d - Sd_0$; is the attenuation introduced by the attenuator; a, b, c and d are chain parameters of the attenuator, which take the form of real positive quantities for the case of a resistive attenuator; a_0, b_0, c_0 and d_0 are the initial chain parameters for the initial mode (when $s = 1$); $\bar{a}_m$, b_m, $\bar{c}_m$, and $\bar{d}_m$ are real, arbitrarily chosen coefficients; $Z_Г$ and $Z_Н$ [$Z_Г = Z_{generator}$, $Z_Н = Z_{load}$] are the complex impendances of the four-pole networks adjacent to the attenuator.

We shall conventionally call control of the transmission factor with a stable frequency response nondistorting control. We shall analyze the procedure for synthesizing channels with nondistorting resistive attenuators for a specified frequency response. Two formulations of the problem are possible:

1) The structure of the channel and the parameters of its components are specified, i.e., the equations of the channel (1) are known, as are $Z_{gen}(p)$ and $Z_{load}(p)$;

2) The structure of the channel is varied for the purpose of simultaneously satisfying the requirements for nondistorting control and a specified frequency response.

Channels with a specified structure. The nominal (in the absence of the attenuator) and the maximal (when the attenuator is inserted in the initial mode) transmission factors of a channel (Figure 1) are defined as:

$$K_{nom} = K_{ном} = Z_н/(Z_г + Z_н),$$

$$K_{max} = K_{макс} = Z_н/(a_0 Z_н + b_0 + c_0 Z_г Z_н + d_0 Z_г).$$

It can be seen from a comparison of these expressions at $K_{nom} = K_{max}$, if the initial parameters of the attenuator are chosen as follows:

$$a_0 = d_0 = 1; \quad b_0 = 0; \quad c_0 = 0, \tag{3}$$

i.e., inserting the attenuator with the initial parameters (3) does not change the shape of the frequency response of the channel. A necessary condition for this choice is the observance of the inequality $(\bar{a}_m - \bar{d}_m)^2 + 4\bar{b}_m\bar{c}_m \geq 0$. If the latter condition is not met, then the initial parameters must be increased. However, this leads to nondistorting control with a frequency response which differs from that specified. To compensate for this change, as well as in the case where equation (1) is not met at the chosen insertion point for the attenuator, it is necessary to use correcting networks. The new impedances of the channel Z'_{gen} and Z'_{load} should provide for the possibility of nondistorting control, while the shape of the frequency response should agree with that specified within the precision of the constant factor $k \geq 1$, i.e., $K_{max} = K_{nom}/k$. For several methods of inserting the correcting networks Z_i and Y_i (Figure 2), the corresponding systems of equations have been derived, from which the parameters of the correcting networks are determined and are given in the table.

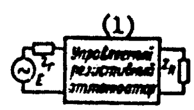


Figure 1.

Key: 1. Controlled resistive attenuator.

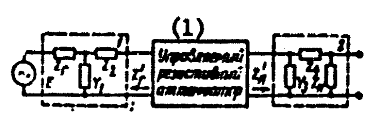


Figure 2.

Key: 1. Controlled resistive attenuator.

Taking into account what has been said, one can propose the following procedure for solving the problem of nondistorting control for a channel with a specified structure:

1. The selection of the point of insertion of the attenuator.
2. Check for the observance of condition (1) (see [2]).
3. The selection of the method of channel equalization and the solution of the system of equations to determine theparameters of the correcting networks (see the table), if (1) is not met.

4. The selection of the coefficients $\bar{a}_m$, $\bar{b}_m$, $\bar{c}_m$, $\bar{d}_m$ and the initial parameters a_0, b_0, c_0 and d_0 from the conditions for the physical feasibility of the correcting networks [3]. The coefficients $\bar{a}_m$, $\bar{b}_m$, $\bar{c}_m$ and $\bar{d}_m$ can taken on any real values, while in the selection of a_0, b_0, c_0 and d_0, it is necessary to take into account the well-known limitations: $a_0 \geq 1$, $b_0 \geq 0$, $c_0 \geq 0$, and $d_0 \geq 1$, as well as the reciprocity condition [3]:

$$a_0 d_0 - b_0 c_0 = 1. \tag{4}$$

5. The selection of the attenuator circuit and the determination of the laws governing the change in its components as a function of the attenuation $W_1(S)$, by means of substituting the chain parameters in (2) and solving the system of equations.

6. Checking for attenuator passivity, i.e., the conditions $W_1 \geq 0$ when $S \geq 1$. If the conditions are not met, it is necessary to change the initial data (paragraphs 3 and 4).

7. The realization of the requisite laws $W_1(S)$.

8. The synthesis of the correcting networks by well-known methods [3].

If condition (1) is not met at the point of attenuator insertion where $b_m \neq 0$ and $c_m \neq 0$, then having chosen (3), the possibility of synthesizing an attenuator which does not change the shape of the channel frequency response in the initial state is to be checked.

Channels with a purposefully variable structure. In this case, the parameters of four-pole networks 1 and 2 (Figure 2) are chosen so that the requirements for the specified frequency response and the condition for nondistorting control (1) are met simultaneously. The transmission factor of the channel (Figure 2) in the initial mode is defined by the expression:

$$K(p) = 1/(a_0 A_1 A_2 + b_0 A_1 C_2 + c_0 B_1 A_2 + d_0 B_1 C_2), \tag{5}$$

where A_1, B_1 and A_2, C_2 are the complex chain parameters of four-pole networks 1 and 2 respectively.

We obtain the following from (1), taking into account the known equalities $Z'_{gen} = B_1/A_1$ and $Z'_{load} = A_2/C_2$:

$$\bar{a}_m A_1 A_2 + \bar{b}_m A_1 C_2 + \bar{c}_m B_1 A_2 + \bar{d}_m B_1 C_2 = 0. \tag{6}$$

Equations (5) and (6) are the initial ones for the synthesis of four-pole networks 1 and 2. Based on what has been presented here, the following procedure can be proposed:

1. The selection of the coefficients $\bar{a}_m$, $\bar{b}_m$, $\bar{c}_m$ and $\bar{d}_m$.

2. The selection of the initial parameters of the attenuator (see above).

3. The selection of the channel structure (in a sequence from the simplest to the most complex).

4. The solution of equations (5) and (6) for the parameters of the four-pole networks 1 and 2 (Figure 2).

The subsequent synthesis sequence coincides with the preceding case (paragraphs 5 - 8). We shall illustrate the procedure for the application of the proposed method using an example.

Table

Исходные данные (1)	$K_{ном}$ K nom.	$K_{макс}$ K max.	Обозначения Symbols	Система уравнений для определения параметров корректирующих цепей из условий НР и (2) $K_{макс} = K_{ном}/k$
$Y_1 = 0$ $Y_3 = 0$	$\frac{Z_н}{Z_г + Z_н}$	$\frac{Z_н}{Z'_0}$	$Z'_0 = a_0 Z'_н + b_0 +$ $+ c_0 Z'_г Z'_н + d_0 Z'_н$ $Z'_г = Z_г + Z_1, Z'_н =$ $= Z_н + Z_4$	$\bar{a}_m Z'_н + \bar{b}_m + \bar{c}_m Z'_г Z'_н +$ $+ \bar{d}_m Z'_г = 0$ $Z'_0 = k\,(Z_г + Z_н)$
$Z_1 = 0$ $Z_4 = 0$	$\frac{Y_г}{Y_г + Y_н}$	$\frac{Y_г}{Y'_0}$	$Y'_0 = a_0 Y'_г + b_0 Y'_г Y'_н +$ $+ c_0 + d_0 Y'_н$ $Y'_г = Y_г + Y_1, Y'_н =$ $= Y_н + Y_3$ $Y_г = 1/Z_г, Y_н = 1/Z_н$	$\bar{a}_m Y'_г + \bar{b}_m Y'_г Y'_н + \bar{c}_m +$ $+ \bar{d}_m Y'_н = 0$ $Y'_0 = k\,(Y_г + Y_н)$
$Z_1 = 0$ $Y_3 = 0$	$\frac{Y_г Z_н}{1 + Y_г Z_н}$	$\frac{Y_г Z_н}{P'_0}$	$P'_0 = a_0 Y'_г Z'_н + b_0 Y'_г +$ $+ c_0 Z'_н + d_0$ $Y'_г = Y_г + Y_1, Z'_н = Z_н +$ $+ Z_4, Y_г = 1/Z_г$	$\bar{a}_m Y'_г Z'_н + \bar{b}_m Y'_г +$ $+ \bar{c}_m Z'_н + \bar{d}_m = 0$ $P'_0 = k\,(1 + Y_г Z_н)$
$Y_1 = 0$ $Z_4 = 0$	$\frac{1}{1 + Z_г Y_н}$	$\frac{1}{Q'_0}$	$Q'_0 = a_0 + b_0 Y'_н +$ $+ c_0 Z'_г + d_0 Z'_г Y'_н$ $Z'_г = Z_г + Z_1, Y'_н =$ $= Y_н + Y_3, Y_н = 1/Z_н$	$\bar{a}_m + \bar{b}_m Y'_н + \bar{c}_m Z'_г +$ $+ \bar{d}_m Z'_г Y'_н = 0$ $Q'_0 = k\,(1 + Z_г Y_н)$

Г = Generator; Н = Load.

Key: 1. Initial data;
2. System of equations to determine the parameters of the correcting networks from the conditions for non-distorting control and $K_{max} = K_{nom}/k$.

Example. Required is the synthesis of a channel with identical impedances Z'_{gen} and Z'_{load}, an internal resistance of the signal source R_{gen} and a transfer function of the form $K(p) = K_0/(1 + \beta_1 p + \beta_2 p^2)$.

We shall choose the values of the initial parameters a_0, $c_0 = 1/r_0 = g_0$, d_0, and determine b_0 from (4): $b_0 = (a_0 d_0 - 1) r_0$. Then, taking into account the equality $Z'_{gen} = Z'_{load}$ ($\bar{a}_m = 1$, $\bar{b}_m = 0$, $\bar{c}_m = 0$ and $\bar{d}_m = -1$), based on (5) and (6), we derive the system of equations:

$$a_0 A_1 A_2 + (a_0 d_0 - 1) r_0 A_1 C_2 + g_0 B_1 A_2 + d_0 B_1 C_2 = 1/K(p);\quad A_1 A_2 - B_1 C_2 = 0. \tag{7}$$

We shall choose the simplest structure of a channel which contains only the element $Z_{gen} = R_{gen}$, and two two-pole networks Y_1, and Z_{load} with a complex conductance (Figure 2). Then, from the conditions of the problem, we find $Y_{load} = 1/Z_{load} = G_{gen} + Y_1$, where $G_{gen} = 1/R_{gen}$, i.e., the admittance Y_{load} contains a resistive component. By employing the chain parameters of four-pole networks 1 and 2 ($A_1 = 1 + R_{gen} Y_1$, $B_1 = R_{gen}$, $A_2 = 1$ and $C_2 = Y_{load}$), taking into account the symbol $y_1 = r_0 Y_1$, we derive from (7):

$$y_1 = \frac{-K_0[2\alpha(a_0 + d_0) + H] + \sqrt{\alpha K_0(\gamma K_0 E + H + \beta_1 H p + \beta_2 H p^2)}}{\alpha K_0 H}, \tag{8}$$

where $E = 4 + (a_0 - d_0)^2$; $H = 4(a_0 d_0 - 1)$; $\alpha = R_r/r_0$.

The function $y_1(p)$ should be rational-fractional [3], and for this reason, the expression under the square root sign in (8) should be a square. Writing $\alpha K_0 = (\gamma - 1)H, E$, where $\gamma = \beta_1^2/4\beta_2$, and designating $N = E/(\gamma - 1)$, we obtain

$$y_1 = \frac{1}{H}[2\sqrt{\gamma N} - 2(a_0 + d_0) - K_0 N + 2\sqrt{\beta_2 N}\, p].$$

We shall choose the maximum possible value $K_0 = K_{0M} = 2(\sqrt{\gamma N} - a_0 - d_0)/N$, in which the circuit y_1 does not contain negative elements. Then $y_1 = 2p\sqrt{\beta_2 N}/H$, i.e., the two-pole network Y_1 has a capacitive admittance pC_1, where $C_1 = 2\sqrt{\beta_2 N}/H r_0$, $r_0 = 2(\sqrt{\gamma N} - a_0 - d_0)R_{gen}/N$. The two-pole network Z_{load} consists of R_{gen} and C_1 connected in parallel.

As follows from the example treated here, the structure selected for the channel provides for the possibility of realizing the specified transfer function with the following limitations on the coefficients β_1 and β_2:

$$\frac{(a_0 + d_0)^2}{4(a_0 d_0 - 1)} > \frac{\beta_1^2}{4\beta_2} > 1.$$

If β_1 and β_2 do not satisfy the limitations indicated above, then the solution of the problem must be carried out for another channel structure.

BIBLIOGRAPHY

1. G.M. Krylov, F.A. Smirnov, A.P. Volkoyedov, V.N. Gubarchuk, "Printsipy i metody regulirovki usileniya v tranzistornykh usilitelyakh" ["Principles and Methods of Gain Control in Transistor Amplifiers"], Second Edition, Moscow, Energiya Publishers, 1974.

2. N.I. Okulich, RADIOTEKHNIKA, 1978, Vol 33, No 9.

3. N. Balabanyan, "Sintez elektricheskikh tsepey" ["Electrical Network Synthesis"], Moscow - Leningrad, Gosenergoizdat Publishers, 1961.

8225
CSO:1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.372

ON THE RELATIONSHIPS WHICH RELATE THE CHARACTERISTICS OF THE TRANSIENT AND STEADY-STATE MODES OF LINEAR SYSTEMS

Moscow RADIOTEKHNIKA in Russian Vol 33 No 12, Dec 78 pp 74-76

[Article by M.Z. Chapovskiy, manuscript received 13 February, 1978]

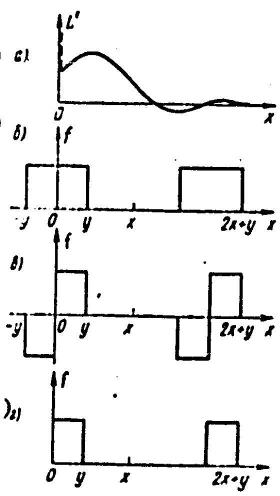
[Text] The well-known expressions, which were derived by breaking down into periods the response to a pulsed input action [1] or a cutoff function in the form of a rectangular pulse [2], allow for the calculation of the transient $h(t)$ and pulse $a(t)$ characteristics of a linear system from the real $K_r(\omega)$ and imaginary $K_i(\omega)$ components of its transfer characteristic which are specified in analytical form $K(i\omega) = K_r(\omega) + iK_i(\omega)$, the absolute value of which $|K(i\omega)| \to 0$ when $\omega \to \infty$. Many linear systems do not satisfy this limiting condition.

a)

b)

c)

d)



General computational expressions in the form of rapidly converging series are derived below, which relate the characteristics of the transient and steady-state modes of a linear system, which are freed of the limitation imposed on the behavior of $|K(i\omega)|$ when $\omega \to \infty$; the well-known expressions [1, 2] are special cases. The basis of the approach is the substitution of a piecewise continuous function for the continuous pulse characteristics of the system or the derivatives of the real and imaginary parts of its transfer characteristic, where this function coincides with the indicated characteristic in a specified manner in selected time intervals which follow one another in a periodic fashion.

We shall consider a function $L(y)$, which is generally different from zero when $y \geq 0$; in the corresponding cases, we shall equate it to $h(t)$, $K_r(\omega)$ or $K_i(\omega)$. The derivative of this function (Figure 1a) contains in its makeup a δ function (conventionally shown by the dashed line) and is related to L(y) by the integral expression:

$$L(y) = L(0) + \int_{0_+}^{y} L'(x)\,dx = L(0) + L_+(y), \tag{1}$$

where "+" means that the integration is carried out for positive values of y, excluding y = 0.

In a manner similar to [2], we multiply L'(x) (Figure 1a) by the function f(x), which takes the form of a periodic sequence of pulses (Figure 1b, c and d) with a unit amplitude, a repetition period of 2X, and a width determined by the quantity y. In this case, the function (1) can be written in the form:

$$L(y) = L(0) + \int_{0_+}^{\infty} L'(x)\,f(x)\,dx - \Delta_i, \tag{2}$$

where Δ_i, depending on the waveform of the pulse (see Figures 1b, c and d) has values of the following respectively:

$$\sum_{n=1}^{\infty}[L(2nX+y)-L(2nX-y)],\quad \sum_{n=1}^{\infty}[L(2nX+y)+L(2nX-y)-2L(2nX)],$$

$$\sum_{n=1}^{\infty}[L(2nX+y)-L(2nX)].$$

We shall represent the function f(x) in the form of the corresponding trigonometric series:

$$f(x)=\begin{cases}\dfrac{x}{X}+\dfrac{2}{\pi}\displaystyle\sum_{k=1}^{\infty}\dfrac{\sin\frac{k\pi}{X}y}{k}\cos\dfrac{k\pi}{X}x & \text{(рис. 1б), (Figure 1b)}\\[2ex] \dfrac{2}{\pi}\displaystyle\sum_{k=1}^{\infty}\dfrac{1-\cos\frac{k\pi}{X}y}{k}\sin\dfrac{k\pi}{X}x & \text{(рис. 1в), (Figure 1c)}\\[2ex] \dfrac{x}{2X}+\dfrac{1}{\pi}\displaystyle\sum_{k=1}^{\infty}\dfrac{1}{k}\left(1+\sin\dfrac{k\pi}{X}y\cos\dfrac{k\pi}{X}x-\cos\dfrac{k\pi}{X}y\sin\dfrac{k\pi}{X}x\right) & \text{(Fig. 1d) (рис. 1г).}\end{cases} \tag{3}$$

If the function L(y) is equated to the transient characteristic, while L'(x) is equated to the pulse characteristic, then it is necessary to establish the following correspondences: y is the time t, X corresponds to the time interval T during which the transient process in the linear system is practically completed, while x corresponds to a certain integration variable τ. By substituting (3) in (2) in making use of integral Fourier transforms, as well as theorems on the initial and finite values of the original and the transform, we find:

$$h(t)+\sum_{n=1}^{\infty}[h(2nT+t)-h(2nT-t)]=K(\infty)+\frac{t}{T}[K(0)-K(\infty)]+$$

$$+\frac{2}{\pi}\sum_{k=1}^{\infty}\left[K_{\text{д}}\left(\frac{k\pi}{T}\right)-K(\infty)\right]\frac{\sin\frac{k\pi}{T}t}{k}, \qquad (4)$$

$$h(t)+\sum_{n=1}^{\infty}[h(2nT+t)+h(2nT-t)-2h(2nT)]=$$

$$=K(\infty)-\frac{2}{\pi}\sum_{k=1}^{\infty}K_{\text{м}}\left(\frac{k\pi}{T}\right)\frac{1-\cos\frac{k\pi}{T}t}{k}. \quad \begin{matrix}[K_{\text{М}}=K_i]\\ [K_{\text{Д}}=K_r]\end{matrix} \qquad (5)$$

The third expression for h(t) coincides with the half-sum expressions of (4) and (5).

When T increases, the expressions under the summation sign on the left side in (4) and (5) fall off rapidly because of the strong attenuation of the actual pulse characteristics of linear systems. For this reason, from the right side of expression (4) and (5), or their half-sum, one can determine approximately with any degree of precision the value of the transient characteristic h(t) at any point in time from the same readouts of the $K_r(\omega)$ and/or $K_i(\omega)$, taken every other discrete frequency interval $\Delta\omega = \pi/T$. The choice of the quantity T and the estimate of the approximation error are carried out in a manner similar to [2].

When $T \to \infty$, expressions (4) and (5) change into the well-known integral expressions of [3]. When $t \to \infty$, the limit of their left side terms is h(0), while for the right side, is the quantity $K(\infty) = \lim_{\omega\to\infty} |K(i\omega)| = K_r(\infty)$. The behavior of h(t) when $t \to \infty$ can be established in the following fashion. If y tends to $y \to X(t + T)$, or $y \to 2X(t + 2T)$ (see Figure 1b or 1d), then the pulses come closer together and the pulse sequence changes into a unit step. The value of the function under this condition will be the same as when $t \to \infty$. Substituting t in (4) instead of T, we obtain:

$$h(T)=\lim_{t\to\infty}h(t)=h(\infty)=\lim_{\omega\to 0}|K(i\omega)|=K(0)=K_{\text{д}}(0).$$

Finally, in the special case for linear systems for which $K(\infty) = 0$, expression (4) coincides with the corresponding expression from [2].

Of considerable importance in calculations using (4) and (5) is the convergence of the series incorporated in them, which decay by no worse than

$1/k^3$ and $1/k^2$ respectively. It can be improved [4] if the series with comparatively slowly decreasing terms, the infinite sums of which are tabulated in [5], are isolated from the series with the oscillating terms.

If the function $L(y)$ is equated with the real $K_r(\omega)$ or the imaginary $K_i(\omega)$ components of the transfer characteristic, then the following substitutions should be made in the expression given above: y corresponds to the frequency ω, X to the frequency interval Ω, within the limits of which the process is practically concentrated, where this process is described by the derivative of the function $K_r(\omega)$ or $K_i(\omega)$, while x corresponds to some variable of integration ν. In this case, we multiply the derivative of $K_r(\omega)$ by the cutoff periodic function shown in Figure 1c, while we multiply the derivative of $K_i(\omega)$ by the function shown in Figure 1b.

Making use of the formula for integration by parts, we obtain:

$$K_{\text{д}}(\omega)+\sum_{n=1}^{\infty}\left[K_{\text{д}}(2n\Omega+\omega)+K_{\text{д}}(2n\Omega-\omega)-2K_{\text{д}}(2n\Omega)\right]= h(\infty)-\sum_{k=1}^{\infty}\frac{\pi}{\Omega}a\left(\frac{k\pi}{\Omega}\right)\left[1-\cos\frac{k\pi}{\Omega}\omega\right], \tag{6}$$

$$K_{\text{м}}(\omega)+\sum_{k=1}^{\infty}\left[K_{\text{м}}(2n\Omega+\omega)-K_{\text{м}}(2n\Omega-\omega)\right]=-\sum_{k=1}^{\infty}\frac{\pi}{\Omega}a\left(\frac{k\pi}{\Omega}\right)\sin\frac{k\pi}{\Omega}\omega. \tag{7}$$

From the right part of these equations, one can calculate with any requisite degree of accuracy the value of $K_r(\omega)$ or $K_i(\omega)$ for a frequency ω contained in the range of frequencies from 0 to Ω, based on the same readouts of the pulse characteristic $a(t)$ taken every other time interval π/Ω. An analysis of the resulting expressions, the estimation of the errors and the choice of the quantity Ω were carried out in the same order as in the calculation of $h(t)$. The same general conceptual approach to the improvement of the convergence of the computational process is also retained.

BIBLIOGRAPHY

1. I.G. Mamonkik, "Impul'snyye usiliteli" ["Pulse Amplifiers"], Moscow - Leningrad, Gosenergoizdat Publishers, 1958.

2. I.N. Migulin, AVTOMATIKA I TELEMEKHANIKA, 1963, Vol 24, No 10.

3. S. Seshu, N. Balabanyan, "Analiz lineynykh tsepey" ["Linear Circuits Analysis"], Translation from the English edited by G.I. Atabekov, Moscow - Leningrad, Gosenergoizdat Publishers, 1963.

4. B.P. Demidovich, I.A. Maron, "Osnovy vychislitel'noy matematiki" ["The Fundamentals of Computational Mathematics"], Moscow, Fizmatgiz Publishers, 1963.

5. I.S. Gradshteyn, I.M. Ryzhik, "Tablitsy integralov, summ, ryadov, i proizvedeniy" ["Tables of Integrals, Sums, Series and Products"], Moscow, Fizmatgiz Publishers, 1962.

8225
CSO:1870

GEOPHYSICS, ASTRONOMY AND SPACE

FUTURE COURSE OF SOVIET MANNED SPACE FLIGHT DISCUSSED

Paris AIR & COSMOS in French 10 Feb 79 pp 38-40

[Article by Albert Durocq]

[Text] The Soviets undoubtedly changed their plans last autumn. We became aware of this from both their decision to defer performance of the French-Soviet ELMA experiment devoted to preparation of materials in space by use of the furnaces of a Salyut--an experiment which, last September, was expected to be performed during the last quarter of 1978--and by their expressed desire to devote several months to a "general check" of Salyut 6.

The action was probably not fortuitous. As a matter of fact, everything leads to the belief that it was imposed by modification of a space program whose pages may now be turned rather rapidly; while it is true that the Soviets are making haste slowly, the year 1979 promises to let us witness events much different from those of 1978.

The objective in the year past was elongation of the duration of flight and in this respect events surpassed expectations. We were not surprised to see Romanenko and Grechko achieve a flight of 96 days from 10 December 1977 to 16 March 1978: the increase in performance compared to the record set 4 years earlier by the Americans was moderate. In contrast, we were astonished when, without waiting even 3 months, the Russians did not hesitate to launch Kovalenok and Ivanchenkov to remain in space for 139 days.

We have, in fact, explained that man is not a machine, or rather he is a transcendent machine whose complexity precludes expression by equations. It is possible to extrapolate results over a short period; it is impossible to predict the behavior of the organism during a prolonged time under unaccustomed conditions; only experience makes it possible to ascertain the effectiveness of measures that have been taken and, additionally, indicate those which may enable the following step to be achieved.

Future 6-month Flight

After the 3-month flight the normal step would have been a 4-month flight. Apparently after hesitating somewhat--they undoubtedly had planned on leaving Kovalenok and Ivanchenkov in space for only 110 to 120 days and thereafter achieve a flight of some 140 days--the Russians took the great chance of right away attaining 4-1/2 months. This was a wager which they won. In contrast, it may be assumed that they probably will not so soon tackle the next step which, of course, would quite naturally be a 6-month flight.

To prepare for this 6-month flight, it is first of all appropriate to exploit in minute detail the results recorded by the numerous apparatus of the technical-medical complex aboard Salyut 6. It will be necessary to study, first, the observations made on board during the 139 days that Kovalenok and Ivanchenkov spent in space and next during their period of readaptation to the earth's gravity, the two men having returned profoundly changed externally and organically. This readaptation was accomplished under favorable conditions, yet for all that, was not accomplished easily: at present, while having resumed their occupations--in fact, this was an essential condition of their readaptation--the cosmonauts remain under medical surveillance.

In other words, the specialists of Soviet space medicine must in the first place examine for a long time the flight and its consequences upon the organisms of the two men. Only then can the lessons be learned which will enable the 6-month flight to be prepared, and let us understand how to establish the infrastructure necessary to such a flight.

This work is of such nature, it seems, that they will be occupied with it for at least a year which is to say that we are not expecting a record flight in 1979.

After all, another consideration enters, in the final accounting: Before the 6-month flight is achieved it will be necessary to design its medical infrastructure.

But a preliminary analysis of the situation seems to have convinced Dr Gazenko and his team of the impossibility of being satisfied, for that infrastructure, with the facilities provided for the Salyut as we have known it up to now, namely a medical chair associated with equipment the complexity of which, since Salyut 1, has always been outstanding, a gymnasium, and use, by the cosmonauts, of a wardrobe of space suits of all kinds.

The Soviet space medicine chief already had his own ideas on the problem. In his opinion the Salyut equipment permitted a flight of 4-1/2 months; it undoubtedly did not permit one of much longer duration. And that is the reason why Dr Gzenko made the decision to surpass the 4-month duration, he having considered it was imperative to exploit to the maximum the capabilities of the Salyut by prolonging the Mission of Kovalenok and Ivanchenkov.

Limitations of the Present Salyut

After the 139-day flight has been studied it must thus be assumed that for the following step the Soviets will use a framework other than the Salyut of yesterday....

This is thoroughly logical.

In the history of the manned flights we first experienced the era of the cabins: they permitted flights the maximum duration of which reached 14 days with the Americans (Gemini 7) and 18 days with the Soviets (Soyuz 9). Strictly speaking, it is conceivable that men could have remained longer in space aboard a cabin but it would have been only a matter of a performance calling upon their capabilities of endurance without any benefit being derived by space medicine. Let it be understood that the specialists would not, from their flight, have gained any valid information making longer missions possible.

The second phase was that of orbiting stations: the Americans without doubt could have remained aboard the Skylab for more than 84 days if there had been sufficient food aboard, the last mission proceeding to the point where there were indications of an unfortunate shortage. After 139 days the facilities of a station of the type Salyut 6 were practically exhausted, the limitation upon flight duration having been imposed not for material reasons--the Progress vehicles were available to bring everything that might have been desired--but for an apparently fundamental reason, namely, the unsuitability of Salyut 6 for longer flights.

Everything has come to pass as though, as far as long manned flights are concerned, the present Salyut has reached the limits of its capabilities...

Experimental Stations

Such words as these may be astonishing. Do we not remember the recent Soviet statements letting it be understood that there was a strong likelihood that use of the Salyut would continue to 1982?

Certainly, but that is precisely the occasion to take a step back in order to evaluate this Salyut program which, begun in 1971, is now going to make us live through its third stage, a program aimed solely, let us not forget, at establishing experimental stations. With Salyut the Russians intended to do many things precluded in the era of cabins in order to perfect the techniques making possible the development of a third generation of manned satellites. We assume in such case, judging from an increased number of Soviet statements in this regard, that after the cabin and single-unit station, this third generation will be modular stations. Therein is the clue through the Salyut program: to effect the required number of experiments to permit preparation of assembled stations.

And we must ask ourselves whether at present the Russians, with their Salyut, have accomplished all those experiments for preparation of the modular station.

Progress at Le Bourget

They have accomplished a certain number of them and, in particular, the past year has given them the opportunity of perfecting the technology of the Progress supply vehicle which soon, without doubt, may be viewed: we go so far as to say that we shall see it at the Le Bourget Salon in June in the Soviet space pavilion and no one doubts that it will be a great success with the curious.

As a matter of fact we know its structure. In front the Progress includes an elongated orbiting compartment; it did not retain a spherical shape; the Russians designed it as an ellipsoid of revolution, with major axis of 3.2 meters and minor axis of 2.6 meters in order to obtain maximum volume within the constraints of cross-section imposed by the launcher. This orbiting compartment became the freight car within which were placed packages and bulk objects of all kinds. Behind it the Soyuz cabin was replaced by a supply module formed by two conical frustums formed at their larger diameters; this module was occupied by containers of all sorts in the form of carbays of various sizes. Last, the engine room, or "conglomerate module," was itself lengthened--its length increased to 4.8 meters--the whole having an appearance which is rugged, thin and graceful. It appears that the Progress is perfected and the Soviets have every reason to be satisfied with the four experiments which they carried out in 1978 with this vehicle, the well known utilization of which has provided them with the accomplishment of long manned flights.

Then, again, perhaps the Salyut program is completed at the present time so far as duration of flight is concerned. We believe that the maximum was probably realized last year with Salyut 6.

What Remains To Be Done

On the other hand, with regard to replacement of crews--a new crew coming on board the station before the crew which occupies it returns--the permanent station concept has not yet been tested.

Moreover, a great mass of work is certainly still to be done in order to give some idea of all the possibilities that exploitation of space will offer: a large series of relatively short flights can be expected during the next 3 years, even if only under the banner of the Intercosmos program.

Above all, practically everything remains yet to be done in the matter of coupling stations. "I am working on it," Chonine told us not long ago.

Preparation of this coupled assembly is going to require two kinds of operations, no part of which has yet been accomplished with Salyut.

First is the matter of bringing two large modules together. Soyuz and Progress coupled to Salyut easily. We have not yet witnessed a journey of two Salyut's, the difficulty of the operation residing not in the greater mass of the vehicles--after all, 19 tons to 19 tons should not be worse than 7 tons to 19 tons--but in the necessity, in such an operation, to make the Salyut play an active role. But no Salyut has yet, with men at its command post, been directed toward a vehicle. What is worse, the Soviets have not yet had the occasion to control, from the ground, two Salyut's in the same region of space.

The experiment is made still more unproductive by the small interest that would be held by putting two Salyut's of Salyut 6 type together end to end. The coupling would have the disadvantage of making inoperative two of the four docking places: the combination would provide only one docking place at each end. That would be inadequate for a complex within which 4 to 6 cosmonauts should prove necessary. An obvious solution would be use of lateral docking places: that is a solution which we know the Russians have studied and we have for long believed this to be the one they had decided to adapt for Salyut 6. As a matter of fact they came up against a difficult problem in seeking, upon the exterior wall, a station with "free surfaces" available to receive all that one would wish to install.

Ten Years After Vulcain

The other class of experiments to which we alluded is construction, properly speaking.

A priori, to realize a modular assembly one could be content with the docking units which exist at present. Is this not the simplest solution? It would present the advantage of permitting disassembly.

In fact, we have a replay of the old problem of the nut or the rivet. In conventional mechanics when you must assemble two pieces you can connect them with bolts and nuts or you want to join them permanently and decide to bond them with adhesive, or even weld them. The nut is of advantage for disassembly. Its use is generally a mistake in permanent structures, first because the weight will be greater, and second, because there is always the danger that the nut will loosen.

These considerations assume even greater importance in space where weight is enemy No 1 with the result that the solution of multiple docking places would be improper. The danger of loosening, moreover, is doubled in orbit because of the serious problems of air-tightness in the case of manned vehicles. New construction techniques are to be perfected, having recourse either to systems of cotters or to welding. One of the Soyuz 6 missions in 1969 was experimentation with the Vulcain [Vulcan] welding equipment... with the objective of perfecting techniques of construction in space the Soviets told us at the time. Perhaps the 10th anniversary of that exploit will be the occasion for them to test the tools they have succeeded in designing by virtue of the information gained with the three methods of utilizing the Vulcain apparatus.

In other words, after the three spectacular experiments of long duration in 1978 logic should require that in the immediate future the Soviets should make us witnesses to a series of pin-pointed operations in view of these concerns, logic seemingly demanding that, after having resolved the most difficult problems--directly concerned with the sojourn of men in space--they set themselves to ask of cosmonauts all that may be accomplished with the facilities which they have available.

11,706
CSO: 3100

PHYSICS

GENERATION OF SINGLE PULSES OF HIGH-ENERGY LASER EMISSION IN MULTICHANNEL "MIKRON" EQUIPMENT USING LARGE RECTANGULAR NEODYMIUM GLASS

Moscow IZVESTIYA AKADEMII NAUK SSSR, SERIYA FIZICHESKAYA in Russian Vol 42 No 12, 1978 pp 2504-2506

[Article by V. A. Batanov, V. A. Bogatyrev, I. A. Bufetov, S. B. Gusev, B. V. Yershov, P. I. Kolisnichenko, A. N. Malkov, A. M. Prokhorov, V. A. Spiridonov, V. B. Fedorov and V. K. Fomin]

[Text] The development of the "Mikron" high-power multichannel laser with large active elements made of neodymium glass at the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences is reported in this article. The installation is intended for analysis of the interaction of laser radiation with matter.

The main part of the system, which determines the power engineering of the laser, is a large multichannel amplifier, built on rectangular active elements with an aperture of 40 × 240 mm and a length of 720 mm. A beam with a cross section that nearly completely fills the light aperture of the active element is used. Each element is passed by the beam one time. The use of large-aperture light beams in the individual channels provides the output cross section of the active medium necessary for generating nanosecond pulses of radiation with an energy of several kJ using the minimum number of divisions of the beams and sharply reduces the number of elements of the optical system that require independent alignment.

The multipurpose installation, intended for operation in a variety of physical experiments, requires a flexible mechano-optical system. This is accomplished by building the optical system of the laser with a relatively small number of large unified elements, components and assemblies. Two versions of the optical system, one of which has been built, are illustrated in Figure 1 as an example of the capabilities of the instrument.

The circuitry of the first three amplifier stages is identical for both versions of the optical system. One contains seven active elements and a beam breeding system, consisting of four groups of lenses O1 and O2, A1

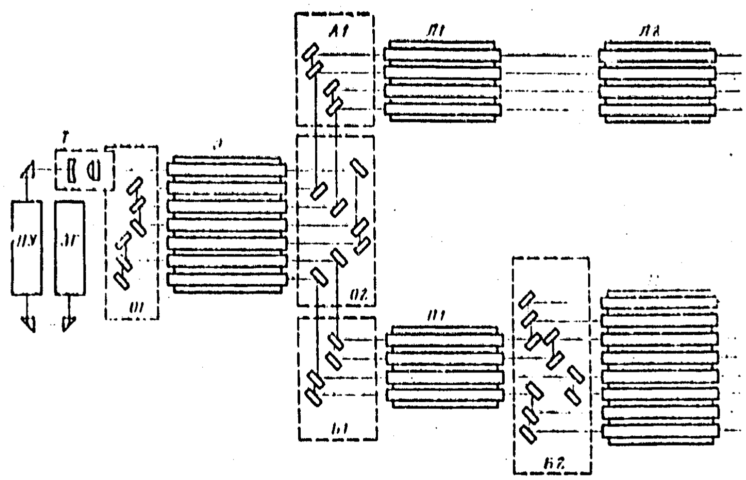


Figure 1. Optical system of "Mikron" laser: ЗГ -- master oscillator; ПУ -- preamplifier; T -- telescope; Э -- active elements of amplifier; O1, O2, A1, Б1 -- beam breeding system; Л1, Л2 -- stages of left arm; П1, П2 -- stages of right arm.

and Б1. Two quads of beams, which pass for further amplification into the left (Л) and right (П) arms of the laser, are formed at the output of the first three stages.

The system that generates 16 beams of radiation (eight in each arm) at the output of the instrument is illustrated by way of example of the right arm. In this version the total cross section area of the active elements of the output stages is $\sim 1.5 \cdot 10^3$ cm^2, which is advantageous for operation in the nanosecond mode at output energies of up to 3-4.5 kJ. At those output energy levels, but with pulse durations of tens of nanoseconds, a simpler system with eight active output elements can be used. Such a system is illustrated in Figure 1 by way of example of the left arm.

The optical pumping system and the component base of the system, which are completely built and functioning, make it possible to build both the first and second versions of the optical system.

The active elements of the power amplifier are installed in Kh-122PM illuminators. Pumping is performed by two layers of IFP-8000 tubes, each with 18 tubes. The discharge pumping circuit consists of two series-connected tubes with a capacitance of 200 μF and an inductance of 100 μH. The limiting energy of each pumping element is 5 kJ per tube. The duration of the pumping light pulse is 0.4 ms at the 0.1 amplitude level. The parameters of the discharge circuit are close to optimum in terms of the stored energy utilization efficiency for the case of amplification of submicrosecond pulses. An ignition pulse is supplied to the envelope of the illuminator. The complete energy capacity of the storage system of the laser is 3.5 MJ.

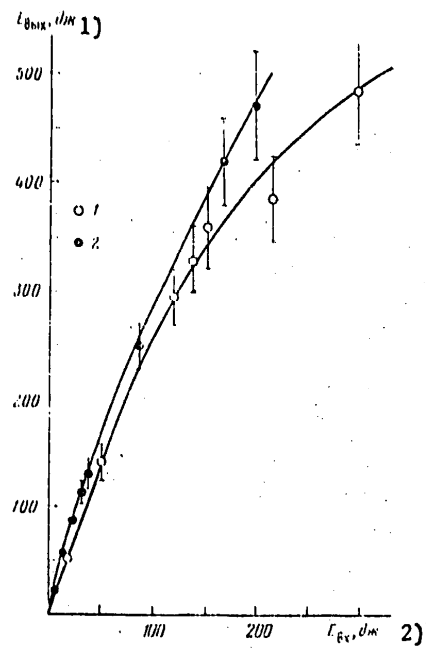


Figure 2. Output energy E_{out} of amplifier stage as function of input energy E_{in}:
1 -- active element in illuminator unit;
2 -- active element in individual illuminator.
KEY: 1. E_{out}, J 2. E_{in}, J

The illuminators that are used in the system are designed so that they can be connected to the units without intermediate reflectors, such that each layer of tubes, except the two outer layers, pumps two active elements at the same time. The two outer layers have flat reflectors made of aluminum foil. The laser is designed so that both the individual illuminators and the units, which include up to eight active elements, can be used.

A version of the optical system with eight output ends (four in each arm, as shown in Figure 1) has been built. Preliminary tests have been conducted for the purpose of analyzing the characteristics of the power amplifier. A master oscillator, in which the Q-factor of the rotating prism is modulated, was used. The radiation of the master oscillator, the resonator of which contained a laminated interference polarizer, was linearly polarized. The master oscillator and the preamplifier are built on GOS-300 and GOS-1000 illuminators.

The beam from the preamplifier stage, with a circular cross section 40 mm in diameter, is transformed by a cylindrical telescope (T) to a beam with an elliptical cross section with axes of 40 and 240 mm.

When a pulse of radiation with a duration of 70 ns at one-half maximum intensity, with an energy of 60 J and a spread of $3 \cdot 10^{-4}$ rad at the output of the system during close to maximum pumping, is fed to the input of the power amplifier, an energy of 3.5 kJ is obtained with a spread within $(4\text{-}6) \cdot 10^{-4}$ rad in the channels at the one-half power level, and 90% of the radiated energy has the original polarization.

Stage by stage amplification of energy in the instrument was measured. The results of the measurements are presented in Figure 2, which shows the output energy as a function of the input energy for one amplifier stage (the bottom curve). The pumping energy is 0.85 of maximum. The amplification of energy in the active elements of these illuminators, with a geometry corresponding to their utilization in the two last amplifier stages (the top curve) was measured for the purpose of forecasting the possible utilization of individual illuminators. The data in Figure 2 can be used for calculating the power engineering of various modifications of the optical system of the "Mikron" instrument. A comparison of the two curves shows that the output energy of the system in this case may reach 4.5 kJ.

7872
CSO: 8144/0956

PHYSICS

UDC 681.7

THE STATE OPTICAL INSTITUTE AND MODERN OPTICS

Leningrad OPTIKO-MEKHANICHESKAYA PROMYSHLENNOST' in Russian No 12, 1978 pp 2-8

[Article by Doctor of Technical Sciences M. M. Miroshnikov, Hero of Socialist Labor]

[Text] The date of 15 December 1918 was the day that the State Optical Institute was organized.

Sixty years ago on this day a meeting of the scientific council of GOI was held in the building of the Physics Institute of Petrograd University at which documents were discussed and ratified on organization of this new institute, prepared by Professor D. S. Rozhdestvenskiy -- a prominent Russian scientist-physicist and subsequently an active member of the USSR Academy of Sciences. At this same meeting D. S. Rozhdestvenskiy was unanimously elected the first director of GOI.

Prior to the Great October Socialist Revolution, there was no developed optical industry and organized science on light and its interaction with matter -- optics -- in Russia. There was no optical glass manufacturing and there were no schools of optical system calculators and only individual specialists were involved in optical engineering, i.e., the science of devices based on optics.

Thus, organization of the State Optical Institute, which took on itself solution of two problems -- conducting scientific investigations in the field of optics and assistance in development of the optical industry -- established the beginning development of scientific and applied optics in our country.

The Soviet Optical School, established on 15 December 1918 at Petrograd during the difficult period of defending the young Soviet republic from foreign interventionists and internal counterrevolution, under conditions of severe economic collapse and famine, laid a reliable base for development of optical glass production, calculation of optical systems, development of optical devices and scientific research in the field of optics.

All this became possible only due to the victory of the Great October Socialist Revolution, which created new socioeconomic conditions for the progress of culture, science and technology.

From the first days of formation of the Soviet government, V. I. Lenin especially emphasized the significance of science for construction of a socialist society. As early as April 1918 in "The Draft of a Plan of Scientific-Technical Investigations," he indicated with maximum clarity the paths of reorganization of industry and accomplishing the economic rise of Russia on the basis of science.

D. S. Rozhdestvenskiy was one of the first Russian scientists to understand the deep progressiveness of these ideas and in the complex situation of an absence of raw material, fuel, provisions and personnel, responded without wavering to V. I. Lenin's call to assist the young Soviet republic in solving the most important problems of state construction.

A specific expression of D. S. Rozhdestvenskiy's aspiration to relate scientific work with the needs of industry, placed on the service of the entire nation, was organization of the State Optical Institute -- a complex scientific institution which bore responsibility not only for the development of science but also for introduction of scientific results into production.

The views of D. S. Rozhdestvenskiy on the need for a close relationship of science to plant practice and the feasibility of complex development of scientific and technical problems in a single institute were subsequently supported by other prominent Soviet scientists -- Academician and later President of the USSR Academy of Sciences S. I. Vavilov, with whose name the activity of GOI was continuously related since 1932 when he replaced D. S. Rozhdestvenskiy in the post of scientific director of the institute. "A continuous line from deeply scientific to specific engineering problems, which relates the puzzles of quantum electrodynamics to difficulties in the technology of the fireclay pot in which optical glass is melted -- this line was and should we feel remain the axis of the Optical Institute," said S. I. Vavilov, appearing at a session of the Academy of Sciences in March 1936.

Due to the constant concern of the Communist Part and the Soviet Government, the State Optical Institute grew, developed and became the largest scientific center, having enriched domestic and worldwide science with outstanding results of investigations obtained in the main directions of physics.

The high scientific level of investigations conducted at the institute was always the basis for supporting the optical industry with new ideas, whose achievements in the majority of cases were related to the activity of GOI.

Being a recognized worldwide scientific center, the State Optical Institute works in close contact with plants on the basis of complex plans for development of science, engineering and technology and also by participating directly in the process of plant production.

The special value of the institute is its highly qualified personnel. The scientific school of GOI is widely known in our country and beyond. Many scientists of GOI were elected members of the USSR Academy of Sciences and of the academies of sciences of the union republics for outstanding scientific services. These are academicians D. S. Rozhdestvenskiy, S. I. Vavilov, I. V. Grebenshchikov, A. A. Lebedev, I. V. Obreimov, V. P. Linnik, A. N. Terenin, V. A. Fok, M. A. Yel'yashevich, A. N. Sevchenko and B. I. Stepanov and corresponding members A. I. Tudorovskiy, T. P. Kravets, D. D. Maksutov, Ye. F. Gross, S. E. Frish, P. P. Feofilov, Yu. N. Denisyuk, G. T. Petrovskiy and V. G. Vafiadi.

The institute's activity has repeatedly received high marks of the Communist Party and the government of the Soviet Union. On the date of its 25th anniversary, 15 December 1943, the State Optical Institute was awarded the Order of Lenin for successful work to create and develop domestic industry and for scientific advances in the field of optics. On 24 February 1976, the institute was awarded the Order of the October Revolution for the results of work during the Ninth Five-Year Plan for high indicators in the field of scientific developments and active participation in development and assimilation of devices and scientific apparatus into serial production. Many research associates of the institute were awarded state premiums and the Lenin and State Prizes.

During the time of existence of the State Optical Institute, the results of its work have been generalized many times. This was done in most complete format in 1968 with regard to the 50th anniversary of the institute.

However, the past 10 years have introduced significant changes in the activity of GOI. These changes are related mainly to two circumstances.

The most recent discoveries in physics, the development of engineering and related fields of knowledge such as electronics, radio engineering and automatics, have significantly enriched optics and we can now talk about a new stage in the development of this science.

Modern optics has become a highly effective means of acting on scientific-technical progress not only due to the fact that it is difficult to cope with different spheres of human activity without it, but also due to the fact that it can solve a number of already postulated problems with greater success than other sciences and branches of technology. This attracted the attention of many academic and branch scientific organizations of the country to optics, by whose efforts important physical and applied problems are being solved.

Under these conditions the State Optical Institute no longer had to be more concerned that any optical problem was studied at the institute, as occurred during all the previous years of its work. The institute's efforts were concentrated on solving the most complex problems, moreover, those which could not be solved by other organizations, and they could be solved at GOI in the best manner due to the presence of the appropriate personnel, the complexity of the institute and its extensive and strong ties to the optical industry.

Moreover, the qualifications increased significantly during the past few years and the level of work of the design offices and the plants of the optical industry was improved.

Many modern optical enterprises have great opportunities to perform not only design, but also scientific work, since they have highly qualified personnel (doctors and candidates of sciences) and well-equipped laboratories at their disposal.

The nature of the institute's relations to industry had to be changed. Operative assistance to the plants remained as before a dependable means of the institute's action on scientific-technical progress in some cases. Moreover, it was also useful for scientific research associates who should not be separated from the plant situation. However, the main form of the institute's influence on industry began to include development of large scientific programs which require assimilation of essentially new ideas and technology and creation of new plants due to the achievement of significant results related to an increase of labor productivity and the quality of the produced products. The fact itself of development and even more implementation of these programs is a powerful stimulus for the interest and progress of production.

The continuously increasing scientific-technical potential and capabilities of optical enterprises created real conditions for releasing GOI of minor investigations of an applied nature, fulfillment of which was previously entrusted to the institute. The most important task of the State Optical Institute will become to an even greater extent universal development of fundamental and research work as bases for determining the paths of the development of optical science and rendering effective assistance to industrial enterprises in development of new, more progressive devices and systems.

We should again recall here that, in asserting the need of the contact of science with production, D. S. Rozhdestvenskiy always felt that it should be based on extensive ideas and associations which lead to intensive development of production. "Science and production have the main task before them -- to create and transfer to the citizens of the USSR as many material and spiritual values as possible. It can be solved by two methods. One method denotes a new increase in the number of workers, new plants and new sites. The second method denotes to simplify and make production less expensive with the same number of workers. Science and GOI should proceed along this second path." Thus spoke D. S. Rozhdestvenskiy, giving the report "The Fate of Optics in the USSR" at the solemn jubilee session on the event of the 15th anniversary of GOI in 1933. He was convinced that a science of a new type would be constructed under conditions of Soviet power.

Very favorable conditions have now been established at GOI in which the institute has become the bearer of a great deal of practical experience and has at its disposal high scientific potential and cadres of scientists capable of solving the most complex scientific problems of today.

To answer the question of what the State Optical Institute is today as a scientific organization and how it differs from other institutes of the country, one must determine those basic trends of research which have either the main position for themselves in the topics of the institute or which are being continuously developed more rapidly due to objective reasons than other trends and which will in the near future occupy the majority role in fundamental research of GOI.

In this regard it is first necessary to note that, despite the appearance of lasers which provide the opportunity to transmit considerable energy of optical radiation over distances during the past few years, the processes of perception, transmission and conversion of information, as before, comprise the basis of optics and of optical instrument building. Spectral analysis of radiatión, absorption and scattering of light by atoms and molecules provides the richest information about the structure of the matter. Optical devices convert and record enormous information flows during measurement of distances and angles, the velocity of motion of bodies, investigation of their shape and so on.

The most efficient method of information transmission, which was previously writing, is the image, which mankind has been using extensively, beginning with cave drawings and masterpieces of painting and ending in photography, television, thermovision and one of the main sections of optics of the future -- holography.

The problem of imaging is the main scientific direction of the work of the State Optical Institute.

From D. S. Rozhdestvenskiy's work on the theory of the image in the microscope and the outstanding achievements of the Soviet school of computer optics and optical engineering to solving the problem of developing infrared "vision" (thermovision), which permits one to see objects in total darkness by their natural radiation, and discovery of the phenomenon of three-dimensional holography, the history of development of the State Optical Institute even today confirms the fruitfulness and prospects of its work on the problem of the image. The general properties of images which determine the roles and purposes of their conversions, processing and reproduction, are now being studied at GOI within the framework of a new scientific trend, which has been named iconics, which is based on the advances of physiological and computer optics, optical engineering, scientific photography, television, thermovision and holography.

The second important scientific trend which determines the face of GOI and the capability of modern optics, is investigations and development of optical materials.

Optical glass, "without which," as D. S. Rozhdestvenskiy said, "there is neither an understanding of nature nor authority over it," was the object of the first investigations and achievements of GOI, due to which in 1927 our country was able to free itself from importing achromatic glass and in 1936 was able to free itself from importing colored optical glass. The entire range of problems related to development of optical materials, investigation of the physical-chemical properties and creation of the technology of industrial production of them, is now being solved at GOI by highly qualified scientific forces.

Traditional research in the field of spectroscopy, luminescence and photochemistry, the sources of which were academicians D. S. Rozhdestvenskiy, S. I. Vavilov and A. N. Terenin, occupy a significant volume in the fundamental research of GOI. These traditional trends are now being supplemented by new content.

New spectroscopic methods of studying plasma worked out by GOI are being developed in the field of atomic spectroscopy.

Main attention is being devoted in the field of molecular spectroscopy to investigations of the intra- and intermolecular relaxation processes.

Mechanisms of energy transfer, emissionless transitions and processes of internal extinction of luminescent centers are being investigated in the field of studying the luminescence of molecules and complexes.

Primary photochemical processes in organic molecules and complexes are being investigated in the field of photochemistry.

Investigations of the new phenomenon of stimulated resonance Raman scattering (RVKR), which provides valuable information about the vibratory transitions in electron-excited molecules and which was discovered at GOI, are being continued in the field of Raman scattering spectroscopy.

Many investigations in the field of spectroscopy, luminescence and photochemistry, initially of only theoretical interest, yielded significant practical results. Thus, new methods and devices for recording superweak magnetic fields originated on the basis of investigations in atomic spectroscopy. New light sources: N-squeezed and laminar pulsed discharges, have been created on the basis of systematic study of plasma properties. The effect of stabilization and destabilization of fluorescence of organic compounds in vapors, discovered and investigated at GOI, has been recognized as an important discovery (B. S. Neporent and N. A. Borisevich). Investigations in luminescence made it possible to develop highly efficient laser emission converters. Cooperative phenomena discovered during spectroscopic investigations in the field of solid-state physics (P. P. Feofilov and V. V. Ovsyankin) are used to visualize infrared radiation. Raman light scattering was useful in study of the glass sitallization process and also in development of lasers with discrete frequency tuning. A new material for phase recording of an optical image (rheoxan), which presents broad opportunities for further development of three-dimensional holography and development on its basis of data storage devices with high recording capacity and methods of correcting wave fronts by using dynamic holograms, has been proposed on the basis of fundamental research of emissionless energy transfer processes with participation of the triplet state of organic molecules, discovered at GOI (A. N. Terenin and V. L. Yermolayev).

All this permits one to regard the trends of investigations in the field of spectroscopy, luminescence and photochemistry, adopted at GOI, very promising, which in combination with other trends of the institute's investigations and its high technological capabilities, yield valuable scientific and applied results.

An important trend of GOI activity, which determines the paths of further progress of optical instrument building, is investigations in the field of unique spectral instrument building and its component base.

The first of them should be called development of the problems of metrology of accurate spectrophotometric measurements. It has been proposed on this basis to develop a complex of a prototype spectrophotometer supported by a system of references and methods of accurate spectrophotometric measurements as a branch metrological base. This complex will permit accurate measurements (10^{-3} of the measured value) of transmission, reflection and scattering spectra in the field of wavelengths of 0.12-40 microns, which is a record in the accuracy and latitude of the spectral range.

A complex of kinetic laser spectroscopy devices is being developed at GOI for direct measurements of rapid relaxation processes, which will permit measurement of absorption, fluorescence and generation spectra and other optical processes in the investigated materials with resolution on the order of picoseconds (10^{-12} s) and nanoseconds (10^{-9} s).

Development of this complex of devices provides the required advancement for industrial spectral instrument building and intensive development of kinetic laser spectroscopy, which is the foundation of the most varied uses of luminous energy. The trend of kinetic spectroscopy is traditional for GOI, since the USSR's first installation for the investigations was constructed in the laboratory of Academician A. N. Terenin at the end of the 1950's and had a time resolution of 100 μs. An installation with resolution of 10^{-9} s is now operating at GOI.

The third important trend of promising spectral instrument building is development of a family of Fourier spectrophotometers at GOI with relatively high time resolution (0.01 s) at high spectral resolution (0.05 cm^{-1}) over a wide spectral range (1-1,000 microns). There is now no doubt of the timeliness of these investigations.

Finally, in talking about unique spectral instrument building, it is impossible not to mention the development of its component base at GOI, primarily production of especially complex and accurate diffraction gratings. Work is being conducted here in the direction of developing a dividing machine and measuring apparatus for cutting diffraction gratings measuring up to 400 x 500 mm and for developing the technology of manufacturing flat and focusing holographic gratings measuring up to 400 x 400 mm.

The broad scientific profile of GOI also makes it possible to conduct investigations in a very timely field related to the search for new photo-recording media. Investigations are being conducted intensively to improve the properties of materials of the ordinary halide-containing photoplate type and also to develop phase-sensitive media which, similar to rheoxan, alter its refractive index rather than absorption of the layer as a result of illumination.

Without continuing further enumeration and without touching on other investigations of the institute in the field of optical instrument building and its component base, one can state with confidence that the dream of the founder of the State Optical Institute D. S. Rozhdestvenskiy that GOI give worthy representation of Soviet science by its achievements and by the scientific forces assembled in it, has been accomplished. This places enormous responsibility on the managers and the entire collective of the institute, who are obligated to be continuously concerned about retention and reinforcement of the composition and scientific potential of the institute and about further improving the efficiency and quality of work.

Science has never and nowhere received such powerful support from society and has not had such favorable conditions for its development as appeared in our country due to the victories of the October Revolution.

General Secretary of the CPSUCC, Chairman of the Presidium of the USSR Supreme Soviet Comrade L. I. Brezhnev has frequently given high marks to the role of science in the development of the productive forces of the country. "There is nothing more practical than good theory," said L. I. Brezhnev from the rostrum of the 25th CPSU Congress. "We know well that the deep flow of scientific-technical progress runs out if it is not constantly fed by fundamental research."

Soviet scientists were always surrounded by concern of the party and government, which has found its clear expression during the past few years in the decisions of the 25th CPSU Congress and in the text of the new Constitution, which guarantees to support the freedom of national creativity by extensive organization of scientific research in our country.

Working at the State Optical Institute, we daily sense this concern in the selfless support which our investigations and developments have always enjoyed.

Therefore, we understand the party management of the intelligentsia by the CPSU primarily as universal support of the creative and social activity of specialists and as the basis of more complete and efficient utilization of their knowledge and experience in the interests of further development of the scientific and technical potential of the country for the good of the people.

The collective of the State Order of Lenin and October Revolution Optical Institute, devoted to the maximum to the ideals of the Great October Socialist Revolution, will answer the concern of the party on development of science with high working efficiency and acceleration of introducing the advances of science into production and the national economy of the country.

6521
CSO: 8144/0977

PHYSICS

UDC 778.39

HOLOGRAPHY INVESTIGATIONS OF THE STATE OPTICAL INSTITUTE

Leningrad OPTIKO-MEKHANICHESKAYA PROMYSHLENNOST' in Russian No 12,1978 signed to press 3 Apr 78 pp 9-13

[Article by Corresponding Member of the USSR Academy of Sciences Yu. N. Denisyuk]

[Text] As noted previously [1], the investigations of the GOI [State Optical Institute] in the field of holography during the period from the time of its appearance through 1967 was characterized mainly by discovery of the more general case of holography with recording in three-dimensional media and development of the theory of this method in so-called kinematic approximation [2-5]. It was intially proposed that holography be used to develop graphic technology, which reproduces the total illusion of the reality of a depicted object, and also holographic diffraction gratings and optical focusing elements. The proposal to develop holographic graphic technology was reinforced by development of special superhigh-resolving photographic plates suitable for recording holograms in counterbeams [6]; the possibility of manufacturing gratings and focusing elements was checked by producing mockups of them using the mentioned photographic plates [3].

The development of holography during the next decade (1967-1977) may generally be characterized by the fact that investigations were essentially completed in development of the scientific foundation of holography with recording in two-dimensional media. Development of a more general method of holography with recording in three-dimensional media proceeded considerably slower mainly due to the absence of adequately efficient media suitable for recording these holograms. This gap has now begun to be compensated to a known degree with regard to development of photopolymers and also media based on polymer materials, whose dispersion varies due to triplet-sensitized transitions ("rheoxan") [7, 8]. However, it is typical that, despite these difficulties, a number of essentially new fields lying at the juncture of holography and nonlinear optics such as traveling intensity-wave holography which occur when the wavelengths of the referent and object beams are different [9] and dynamic holography characterized by the fact that in this case the material reacts to radiation during recording, was determined during the past several years from holography with recording in three-dimensional media; the phenomenon of wave front reversal during stimulated light scattering may also be related to holographic effects.

APPROVED FOR RELEASE: 2007/02/08: CIA-RDP82-00850R000100040023-1

Among the greatest practical achievements of holography, one should note graphic holography with recording in three-dimensional media, where the level of domestic developments considerably exceeded the foreign level [10], and also development of holographic diffraction gratings and focusing elements.

It is typical that in each of the enumerated cases, success was achieved due to the fact that developments essentially reduced to creation of a special, more optimum photographic material for the given problem. Specifically, the "Valenta" and LOI-2 layers were produced sequentially [11, 12] for graphic holography on the basis of [6]. The latter along with the PE-1 layer of N. I. Kirillov is now the most highly resolving among those known in worldwide practice.

One of the promising trends of practical application of holography is development of the three-dimensional holographic moving picture. The main trend in solving this problem is apparently a process in which the exposure is accomplished by ordinary photographic methods in natural light and holograms with recording of the three-dimensional image of the scene are then synthesized on the basis of the data obtained [13, 14]. In this case it has been proposed that a reduction of the frame area on which the recording is made be achieved by using the principles of an aspectogram -- photographic recording of an imaged scene obtained by lens scanning [15, 16].

Let us turn to consideration of more important investigations concerning the named trends. The foundation of holography with recording in two-dimensional media is comprised of the developments:

-- the theory of the effect of the degree of coherence of the recording source of radiation on the hologram and development on this basis of a method of investigating the degree of coherence of the sources [17-20];

-- a method of constructing the image reconstructed by the hologram with variation of the position and wavelength of the restoring radiation source [21-22];

-- a method of recording holograms when the radiation of the referent source is incoherent with respect to the object wave [23, 24].

The following investigations are also related here:

-- the effect of nonlinearity of the photographic material on the characteristics of amplitude holograms [25];

-- some consequences of the theorem of reciprocity in holography [26];

-- the possibilities of scanning an object wave with a detector having arbitrary aperture [27];

-- essential restrictions of signal/noise ratio during holographic reversal of the beam path through a phase inhomogoneous medium [28];

-- the principles of discrete holograms [29];

-- diffraction efficiency and signal-noise ratio of holograms of diffuse objects [30].

Let us note investigations in the field of the principles of holography with recording in three-dimensional media. Theoretical investigations in this direction should include the attempt to relate the structure of a three-dimensional hologram to the structure of the object [31] and to create the so-called mode theory of a three-dimensional hologram which was used to calculate the diffraction efficiency of carrying and reflective holograms, their noise and spectral selectivity [32-37]. The mode theory of a three-dimensional hologram was also successfully used to explain the effect of wave front reversal during stimulated light scattering [34, 35].

Experimental work in this field actually reduced to investigations of light-sensitive media in which the recording was made. Data of studying photochrome glass are presented in [38-41], of studying alkali-halide crystals are presented in [42] and of studying lithium niobate are presented in [43, 44].

Among the fundamental research of halide-containing photomaterials, let us note [45], the author of which discovered abnormal values of the refractive index caused by the presence of colloidal silver in the developed emulsion layer. The remaining papers on investigation of halide photographic plates were presented with consideration of graphic holography.

In the the field of the theory of a dynamic hologram, cases of converting light beams in phase and amplitude media [46-48] were investigated, including conversion of a light wave with random amplitude-phase field distribution to a plane wave [49, 50]. Energy efficiency of beam conversion by holograms with a thermal recording mechanism of approximately 40 percent was achieved experimentally here and an increase of the brightness of a spatially inhomogeneous bundle of beams was realized by using a reflective dynamic homogram [51-53].

Changing to consideration of practical applications, let us dwell primarily on graphic holography. As already noted, the success of domestic developments in this field was the result of intensive investigations of superhigh resolving photographic layers. Methods of measuring the diffraction efficiency of holograms recorded on these layers [54, 55] are given, the effect of synthesis conditions on diffraction efficiency [56] and the effect of developing conditions [57, 58] were investigated and the possibilities of increasing sensitivity by heating [59] were studied.

Investigations of a special film for holography in counterbeams and also of an experimental photolayer with especially high resolution [60] are of interest.

One of the significant prospects of graphic holography is conversion to photography by using pulsed light sources. Papers [61-64] are devoted to investigating the properties of photo materials in the short light pulse mode. In this case the phenomenon of the impingement of the diffraction efficiency of a hologram in the exposure range on the order of nanoseconds [64], detected as a result of the investigations, is of greatest interest. Papers [65-70] are devoted to development and investigation of the parameters of pulsed light sources themselves, designed to record holograms. Successful experiments on recording holographic portraits both in forward and in counter beams [71-74] were conducted on the basis of investigating photo materials and radiation sources.

Let us consider investigations in the field of developing holographic optical elements. Investigations on development of holographic diffraction gratings, first proposed in [3], were subsequently developed in the direction of assimilating methods of manufacturing them; a light-sensitive material for the gratings was studied. Paper [75] was devoted to investigating the optical characteristics of the produced gratings; the permissible variation of the direction of the beam irradiating the grating is considered in [76], while some problems of the surface geometry of the grating and of its aberration are considered in [77]. Investigations to develop focusing elements which reduced to production of light-sensitive material [78] and also investigations on development of copies of diffuse scatterers should be mentioned among developments of other holographic optical elements.

The method of compensating for shifts of the object [79, 80] with respect to recording a set of moving particles [81] was developed in the field of recording high-speed processes and a method of motion picture holography using a traveling acoustic slit in a cavity used in diagnosis of a high-temperature plasma was also proposed.

A cycle of investigations to correct phase distortions introduced by fiber optics located in the object beam [82] was conducted in the field of holographic compensation of image distortions occurring during observation through optically inhomogeneous media and the possibilities of compensating for distortions by the hologram accumulation method [83, 84] using television methods of recording [85, 86] were also studied.

The SIN-1 serial interferometric table, now used extensively [87], was developed to facilitate investigations in the field of holography.

Investigations to develop a three-dimensional holographic motion picture were mainly theoretical in nature and developed in the direction of investigating the properties of aspectograms and of the integrated three-dimensional image restored by using it. The possibility of magnifying the images created by composite holograms and aspectograms, projected through a lens grating was investigated in [88, 89]; the possibility of accomplishing optical filtration of aspectograms was considered in [90] and the principles of aspectograms recorded by using a hexagonal grating were investigated in [91]. The self-reproduction effect, which accompanies projection of an aspectogram through a periodic lens grating, was investigated in [92-95].

Concerning further prospects for development of holography, it should be noted that the problems of holography as a science are apparently being strongly shifted toward the area of detailed study of processes of light interaction with light-sensitive materials and nonlinear media. One should expect development of methods of correcting the wave fronts by using dynamic holograms and also expansion of investigations in the field of three-dimensional holographic memory and three-dimensional motion pictures in the field of promising investigations. With regard to direct practical applications, graphic holography, holographic microfilming and also optical holographic elements of the most diverse designation should achieve extensive introduction here. The basis of these suggestions will be development of the technology of manufacture and chemical treatment of various photographic materials.

More detailed consideration of individual sections of holography is given in surveys on the following topics: general problems of holography [96-99], three-dimensional holography [100], graphic holography and holographic three-dimensional motion pictures [13, 14, 101], optical processing of radio-holograms, holographic methods of compensating for distortions introduced by optically inhomogeneous media and observation through fiber glass.

BIBLIOGRAPHY

1. Denisyuk, Yu. N., OMP, No. 11, 1967.

2. Denisyuk, Yu. N., DAN, Vol. 144, No. 6, 1962.

3. Denisyuk, Yu. N., OPT. I SPEKTR., Vol. 15, 1963.

4. Denisyuk, Yu. N., OPT. I SPEKTR., Vol. 18, 1965.

5. Denisyuk, Yu. N., ZHURN. NAUCHN. I PRIKL. FOTOGR. I KINEMATOGR., Vol. 11, No. 1, 1966.

6. Denisyuk, Yu. N. and R. R. Protas, OPT. I SPEKTR., Vol. 14, No. 5, 1963.

7. Lashkov, G. I. and V. I. Sukhanov, OPT. I SPEKTR., Vol. 44, 1978.

8. Sukhanov, V. I. et al., in "Opticheskaya golografiya" [Optical Holography], Leningrad, Nauka, 1978.

9. Denisyuk, Yu. N., ZHTF, Vol. 44, 1974.

10. Denisyuk, Yu. N., Proceedings of the First European Congress on Optics Applied to Metrology, Strasbourge (France), Vol. 136, December 1977.

11. Zagorskaya, Z. A., OMP, No. 2, 1973.

12. Protas, R. R., Yu. A. Krakau and V. I. Mikhaylova, "Registriruyushchiye sredy dlya golografii" [Recording Media for Holography], Leningrad, Nauka, 1975.

13. Denisyuk, Yu. N., ZHTF, Vol. 43, 1973.

14. Denisyuk, Yu. N., BILD UND TON, Vol. 3, 1974.

15. Denisyuk, Yu. N., ZHTF, Vol. 45, 1975.

16. Denisyuk, Yu. N., OPTICA APPLICATA, Vol. 5, No. 2, 1975.

17. Stasel'ko, D. I., Yu. N. Denisyuk and A. G. Smirnov, OPT. I SPEKTR., Vol. 26, 1969.

18. Stasel'ko, D. I. and Yu. N. Denisyuk, OPT. I SPEKTR., Vol. 28, 1970.

19. Gerke, R. R., Yu. N. Denisyuk and D. I. Stasel'ko, OMP, No. 7, 1971.

20. Denisyuk, Yu. N., D. I. Stasel'ko and R. R. Herke, NOUVELL REVUE D'OPTIQUE APPLIQUEE, Vol. 2, 1970.

21. Denisyuk, Yu. N. and A. P. Gal'pern, OPT. I SPEKTR., Vol. 27, 1969.

22. Gal'pern, A. D. and Yu. N. Denisyuk, OMP, No. 10, 1969.

23. Denisyuk, Yu. N. and D. I. Stasel'ko, DAN, Vol. 176, No. 6, 1967.

24. Davydova, I. N. and Yu. N. Denisyuk, OPT. I SPEKTR., Vol. 26, 1969.

25. Semenov, G. B., Yu. N. Denisyuk and N. A. Savost'yanenko, OPT. I SPEKTR., Vol. 29, 1970.

26. Denisyuk, Yu. N. and M. M. Parkhomenko, OPT. I SPEKTR., Vol. 25, 1968.

27. Denisyuk, Yu. N. and S. I. Soskin, OPT. I SPEKTR., Vol. 31, 1971.

28. Denisyuk, Yu. N. and A. Ikramov, OPT. I SPEKTR., Vol. 41, 1976.

29. Semenov, G. B. and S. M. Koreshev, OPT. I SPEKTR., Vol. 41, 1976.

30. Lokshin, V. I., G. B. Semenov and A. F. Kavtrev, OPT. I SPEKTR., Vol. 36, 1974.

31. Sukhanov, V. I. and Yu. N. Denisyuk, OPT. I SPEKTR., Vol. 28, 1970.

32. Sidorovich, V. G., ZHTF, Vol. 46, 1976.

33. Sidorovich, V. G., OPT. I SPEKTR., Vol. 41, 1976.

34. Sidorovich, V. G., ZHTF, Vol. 46, 1976.

35. Sidorovich, V. G., OPT. I SPEKTR., Vol. 42, 1977.

36. Leshchev, A. A. and V. G. Sidorovich, OPT. I SPEKTR., Vol. 44, 1978.

37. Sidorovich, V. G. and V. V. Sukhanov OPT. I SPEKTR., Vol. 44, 1978.

38. Ashcheulov, Yu. V. and V. I. Sukhanov, OPT. I SPEKTR., Vol. 30, 1971.

39. Ashcheulov, Yu. V. and V. I. Sukhanov, OPT. I SPEKTR., Vol. 34, 1973.

40. Ashcheulov, Yu. V. and V. I. Sukhanov, OPT. I SPEKTR., Vol. 34, 1973.

41. Ashcheulov, Yu. V. et al., in "Registriruyushchiye sredy dlya golografii" [Recording Media for Holography], Leningrad, Nauka, 1975.

42. Arkhangel'skaya, V. A. et al., ZHURN. PRIKL. SPEKTR., Vol. 23, 1975.

43. Sukhanov, V. I., Yu. V. Ashcheulov and A. Ye. Petnikov, OMP, No. 10, 1977.

44. Sukhanov, V. I. et al., in "Opticheskaya golografiya i yeye primeneniya" [Optical Holography and Its Applications], Leningrad, Nauka, 1977.

45. Usanov, Yu. Ye., "Registriruyushchiye sredy dlya golografii," Leningrad, Nauka, 1975.

46. Stasel'ko, D. I. and V. G. Sidorovich, ZHTF, Vol. 44, 1974.

47. Sidorovich, V. G. and Stasel'ko, D. I., ZHTF, Vol. 46, 1976.

48. Stasel'ko, D. I. and Sidorovich, V. G., OPT. I SPEKTR., Vol. 38, 1975.

49. Stasel'ko, D. I. and Sidorovich, V. G., ZHTF, Vol. 44, 1974.

50. Stasel'ko, D. I. and Sidorovich, V. G., ZHTF, Vol. 45, 1975.

51. Bryskiy, V. Z. et al., PIS'MA V ZHTF, Vol. 2, 1976.

52. Dukhovnyy, A. M. and D. I. Stasel'ko, PIS'MA V ZHTF, Vol. 4, No. 6, 1978.

53. Groznyy, A. V. et al., in "Opticheskaya golografiya" [Optical Holography], Leningrad, Nauka, 1978.

54. Denisyuk, Yu. N., V. I. Sukhanov and O. V. Andreyeva, OMP, No. 2, 1970.

55. Sukhanov, V. I. and O. V. Andreyeva, OMP, No. 3, 1972.

56. Andreyeva, O. V. et al., "Problemy golografii" [Problems of Holography], No. 3, Moscow, Mir.

57. Andreyeva, O. V. and V. I. Sukhanov, OPT. I SPEKTR., Vol. 30, 1971.

58. Andreyeva, O. V. et al., ZHURN. NAUCHN. I PRIKL. FOTOGR. I KINEMATOGR., No. 1, 1975.

59. Yaroslavskaya, N. N., O. V. Andreyeva and V. I. Sukhanov, in "Registriruyushchiye sredy dlya golografii," Leningrad, Nauka, 1975.

60. Zagorskaya, Z. A., in "Registriruyushchiye sredy dlya golografii," Leningrad, Nauka, 1975.

61. Stasel'ko, D. I. and A. G. Smirnov, ZHURN. NAUCHN. I PRIKL. FOTOGR. I KINEMATOGR., Vol. 15, 1970.

62. Stasel'ko, D. I. and V. S. Obraztsov, ZHURN. NAUCHN. I PRIKL. FOTOGR. I KINEMATOGR, Vol. 17, 1972.

63. Vorzobova, N. D. and D. I. Stasel'ko, in "Opticheskaya golografiya i yeye primeneniya," Leningrad, Nauka, 1974.

64. Vorzobova, N. D. and D. I. Stasel'ko, OPT. I SPEKTR., Vol. 44, 1978.

65. Stasel'ko, D. I., V. B. Voronin and A. G. Smirnov, OPT. I SPEKTR., Vol. 34, 1973.

66. Stasel'ko, D. I. and V. L. Strigun, OPT. I SPEKTR., Vol. 39, 1975.

67. Aristov, A. V. et al., OPT. I SPEKTR., Vol. 41, 1976.

68. Aristov, A. V. et al., OPT. I SPEKTR., Vol. 43, 1977.

69. Dukhovnyy, A. M. and D. S. Prilezhayev, ZHTF, Vol. 47, 1977.

70. Stasel'ko, D. I., "Opticheskaya golografiya," Leningrad, Nauka, 1975.

71. Stasel'ko, D. I., A. G. Smirnov and Yu. N. Denisyuk, ZHURN. NAUCHN. I PRIKL. FOTOGR. I KINEMATOGR, Vol. 53, 1968.

72. Stasel'ko, D. I., A. G. Smirnov and Yu. N. Denisyuk, OPT. I SPEKTR., Vol. 25, 1968.

73. Stasel'ko, D. I., A. G. Smirnov and Yu. N. Denisyuk, ZHURN. NAUCHN. I PRIKL. FOTOGR. I KINEMATOGR, Vol. 15, 1970.

74. Kuzin, V. A. and D. I. Stasel'ko, in "Opticheskaya golografiya i yeye primeneniya," Leningrad, Nauka, 1978.

75. Gerke, R. R. et al., OMP, No. 2, 1978.

76. Gerke, R. R., OMP, No. 4, 1977.

77. Semenov, G. B., R. R. Gerke and K. A. Stozharova, ZHTF, Vol. 47, 1977.

78. Zagorskaya, Z. A. and S. B. Shevchenko, in "Registriruyushchiye sredy dlya izobrazitel'noy golografii i kinematografii" [Recording Media for Graphic Holography and Kinematography], Leningrad, Nauka, 1978.

79. Denisyuk, Yu. N. and D. I. Stasel'ko, DAN, Vol. 176, 1967.

80. Denisyuk, Yu. N., D. I. Stasel'ko and V. P. Minina, OMP, No. 11, 1968.

81. Stasel'ko, D. I. and V. A. Kosnikovskiy, OPT. I SPEKTR., Vol. 34, 1973.

82. Smirnov, A. G., V. G. Smirnov and D. I. Stasel'ko, Preprint T-0171, Leningrad, NIIEFA, 1972.

83. Kal'nitskaya, T. Ya., G. B. Semenov and V. V. Smirnov, OPT. I SPEKTR., Vol. 44, 1978.

84. Gal'pern, A. D., OPT. I SPEKTR., Vol. 37, 1974.

85. Gal'pern, A. D. and A. S. Sudarushkin, OPT. I SPEKTR., Vol. 40, 1976.

86. Gal'pern, A. D. and A. A. Paramanov, OPT. I SPEKTR., Vol. 37, 1974.

87. Gal'pern, A. D. and A. A. Paramanov, ZHTF, Vol. 46, 1976.

88. Gerke, R. R. et al., OMP, No. 8, 1971.

89. Denisyuk, Yu. N. and I. N. Davydova, ZHTF, Vol. 45, 1975.

90. Denisyuk, Yu. N. and V. P. Bruy, OPT. I SPEKTR., Vol. 43, 1977.

91. Davydova, I. N., ZHTF, Vol. 48, 1978.

92. Davydova, I. N., ZHTF, Vol. 47, 1977.

93. Davydova, I. N., N. M. Ramishvili and V. V. Chavchanidze, OPT. I SPEKTR., Vol. 30, 1971.

94. Smirnov, A. P., OPT. I SPEKTR., Vol. 43, 1977.

95. Smirnov, A. P., OPT. I SPEKTR., Vol. 44, 1978.

96. Smirnov, A. P., in "Opticheskaya golografiya," Leningrad, Nauka, 1978.

97. Denisyuk, Yu. N. and V. I. Sukhanov, UNF, Vol. 15, 1970.

98. Denisyuk, Yu. N., PRIRODA, No. 2, 1971.

99. Denisyuk, Yu. N., VISSENSCHAFT UND FORTSCHRIFT, 23 JAHRGANG, No. 8, 1973.

100. Denisyuk, Yu. N., BILD. VISS., Vol. 10, No. 9, 1973.

101. Denisyuk, Yu. N., in "Opticheskaya golografiya," Leningrad, Nauka, 1978.

102. Denisyuk, Yu. N., INTERKAMERA-73, Prague, 1973.

6521
CSO: 8144/0977

PHYSICS

UDC 535.317.2

MODERN COMPUTER OPTICS AT THE STATE OPTICAL INSTITUTE

Leningrad OPTIKO-MEKHANICHESKAYA PROMYSHLENNOST' in Russian No 12,1978 signed to press 20 Mar 78 pp 36-40

[Article by Doctor of Sciences A. P. Grammatin]

[Text] The leading role in development of computer optics in the Soviet Union belongs to the State Optical Institute. This role has increased especially with regard to introduction of computers into practice. The programs and methods of using computers for optical calculations developed at GOI [State Optical Institute] have achieved wide recognition and distribution at enterprises and in scientific research organizations. Automation of calculations and modeling of the properties of optical systems by using computers have defined a new step in development of computer optics. One can now state that the advances of modern computer optics are inseparably linked to improvement of computer technology. A new qualitative jump in development of this trend has occurred during the past 10 years and was related to transition from the use of low-productive tube computers to semiconductor machines of type BESM-4 and BESM-6 in calculation of optical systems, which permitted not only acceleration of research and development, but also made it possible to expand to a significant degree the volume of information about the different properties of optical systems at the stage of calculation.

The main task of computer optics is to develop designs of optical systems and to determine the numerical values of their parameters on the basis of given properties. Solution of this problem is a creative process which now and in the visible future cannot be completely transferred to machines, since the state of the theory of developing designs and calculation permits the construction of algorithms only for individual stages of the work, heuristic in nature as a whole and based on personal experience and intuition. A computer cannot actively participate in development of optical system designs due to the absence of an analytical or empirical relationship in most cases between the quality of the image and aberrations, on the one hand, and the design of a system and its main characteristics (relative aperture, visual field, focal distance), on the other. These relationships have been found during the past few years only for some special cases of concentric systems [1, 2]. The role of the computer in development of an optical system seems to reduce to answering the question of whether a selected design will provide the required image quality with given main characteristics. Automated correction programs which alter some given design parameters of the system to achieve the necessary degree of correction of aberrations are used to solve this problem (to answer the postulated question). These programs have been subjected to significant redevelopment and considerable improvement during the past decade both in the part of the methods used and in the part of expanding the capabilities and increasing the convenience of use.

The mathematical apparatus of the iterative search for the minimum estimator [3, 4] in automated correction programs. At the beginning of the 1970's, this apparatus was improved mainly by automatic conversion from one method of search to another in the calculation process (for example, from the least squares to the gradient method) and also to the use of experience accumulated during iterations for further reducing the estimator. As indicated by the practice of calculating optical systems, one can, by using these procedures, convert in many cases from a nonoptical local minimum estimator to a more optimum estimator. Unfortunately, the mathematical apparatus used permits one to find only one minimum located in the vicinity of the initial point in solving a single assignment, which does not provide the basis for obtaining an exhaustive answer to the question of the optimum image quality in the optical system selected by the designer. Therefore, the developer must vary both the numerical values of the design parameters and the type of estimator and must resort to the machine repeatedly.

The use of powerful machines having large internal storage made it possible to expand significantly the quantitative capabilities of programs, namely: to increase both the greatest number of surfaces in the corrected systems and the maximum number of factors contained in the estimator and which determine image quality. Real possibilities have appeared for automated correction of optical systems with variable focal distances or magnifications [5]. The range of problems solved by using individual programs has been expanded considerably. Thus, for example, programs for calculating the path of beams and for calculating the refractive indices of optical media along given wavelengths are combined into a single program complex. Similar combining of programs into complexes which simultaneously solve a large number of problems made it possible to reduce the time of developing optical systems.

A significant effect has been achieved by introduction of an automatic error control block into the programs which permits determination of errors committed when recording the design parameters of the system (for example, nonconformity between the number of optical surfaces and the distances between their apexes), initial data for beam calculation and so on. When detecting an error, the machine stops operation and indicates by printout what the error specifically consists of. This permitted a sharp reduction of the time expended to find errors and also freed programmers from the need to be distracted from their main work to check the correctness of assignments.

Introduction of graphic data display devices accomplished during the past few years has made it possible, along with digital data, to produce a drawing of an optical system, the beam path in it and also graphs of aberrations, which provides rapid analysis of the conformity of the optical details to norms with respect to thickness, determination of the vignetting possibilities to correct aberrations, determination of the position of the plane of the best setting, analysis of the extent of higher order aberrations and much more.

The use of highly productive machines made mathematical modeling of a number of properties of optical systems possible and feasible which could previously be determined only with manufacture of experimental prototypes. The number of these properties may include distribution of illuminance in the point image, frequency-contrast characteristics, the effect of manufacturing errors and scattered light on the image quality and so on. The development of computer technology gave a thrust to development of corresponding analytical methods. Methods of numerical determination of ChKKh [Frequency-contrast characteristic] [5, 6], including polychromatic [7, 8], were developed and improved during the past decade. A knowledge of the ChKKh of an optical system makes possible reliable prediction as early as the design stage of both the resolution and properties of the image of the system itself and of the characteristics of complexes which include the object and medium in which it is located, the optical system and the luminous energy detector.

Analytical analysis of the image quality in spectral optical devices in which uncentered optical systems containing spectral prisms or diffraction gratings are usually employed have become possible only with the appearance of computers of sufficiently high productivity. The corresponding formulas and programs were developed for this purpose which permit calculation of the beam path and to determine the apparatus functions in systems with arbitrary arrangement of surfaces in space [9-11]. These programs were very useful in solving other problems, for example, in calculation and investigation of prism systems [12].

The presence of highly productive computers and automated correction programs makes it possible to calculate systems containing aspherical surfaces without special difficulties. However, the need to use aspherics in each specific case should be adequately based with regard to the technological difficulties caused by manufacture and control of these surfaces. A great deal of attention has been devoted during the past decade to this problem at GOI, which has found reflection in [5, 13].

An important property of any optical system is its stability, i.e., its capability of retaining image quality in the presence of specific manufacturing errors. Since finding the total deviations of aberrations caused by manufacturing errors requires a large number of calculations, they were usually not made prior to the introduction of highly productive computers. The manufacturing tolerances were frequently designated by analogy, which sometimes led to rough errors. We now have at our disposal a program which permits one to determine the maximum variations and confidence intervals of variation of aberrations caused by errors of design parameters and scattering [14].

Important advances have been achieved in development of quantitative calculating methods for determining illuminance created in optical devices by scattered light occurring as a result of reflection from the surfaces of optical and mechanical parts [15-18]. Prior to introduction of analytical methods, scattered light was analyzed only upon testing of the experimental model, which frequently did not permit timely implementation of measures to correct it. Cases are known when optical systems had to be redesigned due to the presence of scattered light.

The use of modern computer technology and new methods of calculation has made it possible to achieve important advances in development of new optical systems. One should primarily note the advances in the field of calculating systems with variable focal distances, for example, the objective for a color television camera with 20-fold difference of focal distances [19], "Yantar'" wide-angle pancratic varioobjectives with twofold difference of focal distances [20], the "Granit" objectives [21] and so on. The development of these complex systems became possible due to the use of highly productive computers. Along with specific calculations, a large number of theoretical investigations have been carried out to study the kinematics of pancratic systems of different degree of complexity and to development of methods of calculating them [22-27].

Considerable advances have been achieved in development of optical systems whose image quality is determined by diffraction. These systems include planachromatic and planapochromatic objectives for microscopes [28] and also objectives for photography used in production of microelectronic circuits [6, 29, 30].

Interesting results have been achieved in the field of developing objectives and wide-field telescopic systems having a visual field of 360° in one direction and a field reaching 30° in another [31, 32]. Wide-field systems find application, for example, in checking the inner surfaces of pipes, in observation devices and so on.

Significant results have been achieved in development of high-power and especially high-power objectives [33, 34] and development of methods of calculating them.

Despite the considerable advances achieved in computer optics due to the use of computers, much time is being expended on the development of optical systems which occupies a significant fraction in the total expenditures of time on design of optical devices. To reduce the periods of developing optical systems, it is proposed that the following be carried out:

1. Direct contact of the developer of the optical system with the machine by the use of alphanumeric and graphical displays [35]. The time of waiting

for the results of calculations, which now comprises several hours to days, will be reduced to minutes with this contact.

2. Automatic presentation of technical documentation containing design parameters, summaries and graphs of residual aberrations and also other required information about the optical system by using a computer.

Implementation of these two priority measures will permit a sharp reduction in the time of developing simple optical systems and also systems of medium complexity. Development of optical systems which have a principal innovation will be accelerated to a lesser degree since the main time expenditures in this case will be required on thinking over the results and methods of a further search for solutions. Reducing the periods of developing these systems may be achieved only if the problem of selecting the design of the optical system is solved which could satisfy the postulated requirements. Development of scientific methods which provide feasible selection of the design is the most important task of the near future. To do this, methods may be used which are based on the theory of aberrations, the theory of constructing systems from aplanatic and isoplanatic surfaces [36] and also in combination of these two methods. Moreover, to solve the indicated problem one must carry out investigations directed toward determining the maximum properties of the various types of optical systems, i.e., to establish the theoretical or empirical dependence between the main characteristics of optical systems of specifid type and the image quality, which may be achieved in this case. A knowledge of this dependence will help to a significant degree in facilitating the selection of an optimum design which provides the required image quality.

For optical systems having high image quality and for systems produced in large series, sensitivity to manufacturing errors acquires special significance. Methods of design and calculation of systems, the technologically acceptable errors of which would not lead to significant deterioration of image quality, must be developed. The problem of automatic calculation of tolerances for manufacture of optical systems remains unsolved. The posed tasks require a number of years for solution, but without this transition to a qualitatively new level of development and calculation of optical systems cannot be realized.

BIBLIOGRAPHY

1. Grammatin, A. P. and E. A. Lustberg, OMP, No. 6, 1975.

2. Grammatin, A. P. and A. A. Bagdasarov, OMP, No. 4, 1976.

3. Volosov, D. S. and N. V. Tseno, OPT. I SPEKTR., No. 4, 1968.

4. Grammatin, A. P., OMP, No. 2, 1967.

5. Slyusarev, G. G., "Metody rascheta opticheskikh sistem" [Methods of Calculating Optical Systems], Leningrad, Mashinostroyeniye, 1969.

6. Volosov, D. S., "Fotograficheskaya optika" [Photographic Optics], Moscow, Iskusstvo, 1971.

7. Slyusarev, G. G., OMP, No. 5, 1970.

8. Kraskovskiy, R. A., OMP, No. 7, 1970.

9. Peysakhson, I. V. and V. A. Yefimov, OMP, No. 12, 1970.

10. Peysakhson, I. V., V. Ye. Medvedev and V. A. Yefimov, OMP, No. 10, 1971.

11. Peysakhson, I. V., "Optika spektral'nykh priborov" [The Optics of Spectral Devices], Leningrad, Mashinostroyeniye, 1975.

12. Polyakova, I. P., OMP, No. 12, 1973.

13. Gal'pern, D. Yu., OMP, No. 7, 1971.

14. Grammatin, A. P. and A. B. Degen, OMP, No. 7, 1970.

15. Grammatin, A. P., OMP, No. 6, 1970.

16. Goncharenko, Ye. N., OMP, No. 8, 1971.

17. Goncharenko, Ye. N., OMP, No. 9, 1971.

18. Gal'pern, D. Yu., OMP, No. 2, 1974.

19. Slyusarev, G. G., V. S. Sokolova and V. Ya. Ivanova, Author's certificate No. 490066, BYUL. IZOBR., No. 40, 1975.

20. Gradoboyeva, N. A., OMP, No. 1, 1974.

21. Stefanskiy, M. S., OMP, No. 8, 1970.

22. Shpyakin, M. G., OMP, No. 1, 1970.

23. Polyakova, I. P., OMP, No. 2, 1972.

24. Golovanova, L. N., OMP, No. 10, 1974.

25. Polyakova, I. P. and Ye. S. Poltyreva, OMP, No. 10, 1975.

26. Stefanskiy, M. S. and I. Ye. Isayeva, OMP, No. 7, 1970.

27. Polyakova, I. P., OMP, No. 3, 1977.

28. Panov, V. A. and L. N. Andreyev, "Optika mikroskopov" [The Optics of Microscopes], Leningrad, Mashinostroyeniye, 1976.

29. Grammatin, A. P., R. M. Larina and V. A. Gorbunova, OMP, No. 12, 1974.

30. Grammatin, A. P., R. M. Larina and V. A. Gorbunova, OMP, No. 11, 1976.

31. Goncharenko, Ye. N., OMP, No. 1, 1972.

32. Goncharenko, Ye. N. and G. F. Belyakov, Author's certificate No. 275451, BYUL. IZOBR., No. 22, 1970.

33. Korshunova, L. I., Author's certificate No. 273468, BYUL. IZOBR, No. 20, 1970.

34. Korshunova, L. I., Author's certificate No. 305440, BYUL. IZOBR, No. 18, 1971.

35. Grammatin, A. P. and A. B. Degen, OMP, No. 10, 1974.

36. Rusinov, M. M., "Tekhnicheskaya optika" [Engineering Optics], Mashgiz, 1961.

6521
CSO: 8144/0977

PHYSICS

UDC 666.22+548.0

NEW OPTICAL GLASS AND CRYSTALS

Leningrad OPTIKO-MEKHANICHESKAYA PROMYSHLENNOST' in Russian No 12, 1978 signed to press 11 May 78 pp 13-17

[Article by Corresponding Member of the USSR Academy of Sciences G. T. Petrovskiy]

[Text] Despite the saturation of modern optical instruments with complex electronic circuits, the heart of any optical device which determines its functional capabilities remains the optical element, manufactured from some optical material. Light is used as the main form of energy not only in traditional fields of optics: in microscopy, photography and so on; a number of problems in such branches of the national economy as communications, mechanical and chemical technology and power engineering can be solved more economically and efficiently by using it. This primarily requires an entire complex of optical materials with diverse physical-chemical properties.

Requirements on the properties of optical materials are extremely diverse and are contradictory to a known degree. On the one hand, the optical material should retain its properties when affected by such external factors as variable temperature fields, high beam loads, aggressive chemical media and hard gamma- and neutron radiation. On the other hand, the operating principle of a number of new optical systems is based on the fact that the parameters of the optical medium or of the light wave vary significantly upon interaction of the optical element with the luminous flux or with another type of electromagnetic radiation. The optical media for these devices should provide generation of coherent radiation, variation of the light transmission as a function of luminous flux intensity and rotation of the light beam polarization plane in the magnetic field.

It is of course impossible to reflect everything here that was done over a period of 60 years to develop production of optical glass and optical monocrystals. Therefore, let us dwell on the advances in this field during the past decade. During this period essentially new results were achieved in development of glass which occupy the outer regions in the Abbe diagram, with special path of partial dispersions and with special thermooptical properties. It is very important that it has been possible to produce glass simultaneously combines in itself the special path of dispersion and low thermooptical constants.

L . . IND TECHNOLOGY

10 APRIL 1979 (FOUO 19/79) 2 OF 2

One of the most interesting materials with extreme values of optical constants is FFS2 fluorophosphate glass, which has no analogs in worldwide practice and which was developed by many years of efforts of workers in science and industry. The unique chemical composition (the glass-forming agent is barium monofluorophosphate of a total of 8 percent; the remaining components are fluorides of alkali-earth and rare-earth elements) gives this glass a minimum refractive index (n_2 = 1.43658) and maximum dispersion coefficient (95.8) compared to other industrial glass. The glass has been patented in the GDR, England and France. Unlike monocrystalline fluorides of alkali-earth metals, it has low thermooptical constants ($W = 2\cdot10^{-7}$ deg^{-1}), which is a significant advantage of it. However, it must be noted that very great advances have occurred during the past decade in the technology of monocrystalline fluorides, especially in the field of growing large monocrystals of barium fluoride, calcium fluoride and magnesium fluoride. Calcium fluoride is now produced up to 600 mm in diameter, barium fluoride is produced also up to 600 mm in diameter and magnesium fluoride is produced up to 150 mm in diameter. Magnesium fluoride crystals (sellaite) are grown from a melt by the Stockbarger method in a fluorinating atmosphere. Sellaite is the only optical material which combines transparency in the vacuum ultraviolet region with dual beam refraction due to the anisotropy of the crystalline structure.

Large leucosapphire monocrystals also play an important role in modern optics. The technology of growing these crystals 150-200 mm in diameter and with mass of more than 10 kg has been developed, which exceed the best worldwide specimens in spectral characteristics and structural perfection and which correspond to categories 1 and 2 in optical homogeneity. The refractive index gradient at each point of the boule is not greater than $(0.5-2)\cdot10^{-5}$.

Returning to the problem of producing glass with extreme values of optical constants, we note that the characteristic feature of the past decade may be regarded as total realization of all the capabilities which were already laid in the established rather traditional borolanthanium systems and in new vitreous systems based on germanium and lanthanum oxides. The upper boundary on the Abbe diagram now corresponds approximately to glass with refractive indices of 1.800-1.833-1.872-1.900 and with dispersion coefficients of 45-43-40-37, respectively.

Only several types of glass with low thermooptical constant W: LK1, FK14, FK5, TK22, BF32 and TBF6 was previously known among materials with special thermooptical properties.

Enormous work has been carried out to develop new optical glass with zero and negative values of W, which have been introduced into serial production. As an example we point out TK1621 athermal heavy crown with $W = -13\cdot10^{-7}$ deg^{-1}; TK1419 glass which is an athermal analog of TK14 glass and which has $W = -20\cdot10^{-7}$ deg^{-1} ($W = +56\cdot10^{-7}$ deg^{-1} in TK14) while retaining its main optical constants; BK1008 glass with $W = +10\cdot10^{-7}$ deg^{-1}; BF1320 glass with $W = -20\cdot10^{-7}$ deg^{-1} -- an athermal analog of BF13 marketable optical glass in which $W = 59\cdot10^{-7}$ deg^{-1}.

Glass with optical voltage coefficient equal to zero is required for a number of systems. The possibility of practical production of them was not quite clear previously. The principles of developing these types of glass were refined and realized during the past few years.

It is very interesting to note in this regard how detailed investigation of the photoelastic properties of alkali metal oxides in glass altered the estimate of significance for optical glass manufacture of rubidium and cesium oxides. Previously, when only the effect of these oxides on refractive indices were taken into account, they were not regarded as components which could be introduced into the compositions of optical glass. It has now been determined that rubidium oxide and especially cesium oxide permit production of athermal glass with low optical voltage coefficient and thermooptical constants W, P and Q. Specifically, cesium oxide has the highest absolute value of thermooptical constant (-450×10^{-7} deg^{-1}).

The problem of a significant increase of optical glass transparency during the past few years has been solved not only for lens, but also for fiber optics. The highest requirements with regard to light transmission are placed on glass for fiber-optic communications lines: its absorption in the near IR region of the spectrum should comprise approximately 0.001 percent per centimeter. Light guides having such low absorption as units of decibels per kilometer are an essentially new transmitting medium by means of which problems of information reception and processing can be solved completely differently, up to development of optical computers. The glass of these light guides is one of the rare cases when light losses due to scattering may exceed the losses caused by absorption. Therefore, when developing glass fibers for communications lines, interest in the joint study of Rayleigh scattering and stimulated Mandel'shtam-Brillouiun scattering and in the method of finding regions of inhomogeneity in glass which have dimensions less than those which can be detected by electron microscope methods, should be increased. Glass produced from superpure chemical materials were not simply a more transparent medium from the viewpoint of spectroscopy but were an essentially new material. The color centers exist differently in this glass and energy transmission processes occur differently. One can also point out the curious fact as formation of color centers in especially pure glass due to the effect of ultraviolet radiation of the surface plasma discharge, which specifically permits diagnosis of the brightness temperature of a plasma.

The technology of producing glass transparent in the far IR region of the spectrum has been improved significantly during the past decade. Specifically, the IKS31 and IKS32 crown-flint pair for the IR region, which makes it possible to correct some types of aberrations, has been developed specifically. The thermal increments of the refractive index of oxygen-free chalcogenide glass, which permits calculation of the thermal aberrations of optical systems by using this glass, have recently been determined.

The possibility of coherent radiation generation in neodymium-activated silicate glass was demonstrated as early as 1962. The operating specifics of laser glass requires simultaneous fulfillment of a number of conditions which should be realized in the active material. These are high optical homogeneity, high conversion efficiency of the luminous energy of the pumping lamp, low distortions of the wave front with temperature gradient through the cross-section of the active rod, retention of optical properties at high doses of UV radiation, high transparency with generation length, beam strength, chemical stability and so on. Each of these conditions is rathter difficult to realize. Nevertheless, the development of glass-making technology and spectral-luminescent investigations made it possible to develop 12 marks of industrial neodymium glass. A complex of high indices of quality have been achieved in domestic laser glass: cordless blanks measuring up to 1,200 x 280 x 70 mm, low bubble content (up to 3 bubbles/kg), low nonactive absorption (less than $2 \cdot 10^{-3}$ cm^{-1}), high quantum yield of luminescence (-0.5 to -0.9), low values of thermal wave aberrations (-10^{-6} to 10^{-7} deg^{-1}), retention of generation efficiency after 10^5-10^6 flashes of the pumping lamp, absence of metal inclusions and efficiency up to 4.5 percent.

Both silicate- and phosphate-based laser glass with different activator concentrations are being produced. Compared to phosphate glass, silicate glass has greater thermal stability and greater length of luminescence. Phosphate glass is characterized by higher stimulated emission cross-sections (σ = 3-3.5 x 10^{-20} cm^2) and lower values of thermooptical constants: (P = $2 \cdot 10^{-7}$ and Q = $4 \cdot 10^{-7}$ deg^{-1} (P = $10-30 \cdot 10^{-7}$, Q = $5-9 \cdot 10^{-7}$ deg^{-1} and σ = $1.7-2.5 \cdot 10^{-20}$ cm^2 in silicate glass). Development of neodymium laser glass is proceeding in the direction of reducing the temperature dependence of thermooptical properties, reducing the optical voltage coefficient and further improvement of chemical stability and beam strength. There are greater possibilities for all types of laser glass in the area of improving the thermal strength of the active elements by various types of treating the rods (tempering, ion exchange and protective coatings).

One of the most promising bases for laser glass is now assumed glass containing beryllium fluoride.

The characteristics of beryllium fluoride glass, activated by rare-earth elements, make them a promising material for the active elements of lasers. Successful energy distribution between individual transmissions in emission is provided in them. Generation of stimulated emission in neodymium beryllium fluoride glass was first observed in 1966. The glass is stable to the effect of high beam (optical) loads, since the small increase of the nonlinear refractive index makes it difficult for emission self-focusing to develop and it is stable to hard gamma-radiation mainly due to the high electronegativity of fluorine. Experimental-serial production of beryllium fluoride glass was organized in 1967. Only 10 years after publication of a cycle of our papers, the Corning Company (United States) began to conduct similar investigations of an applied nature.

Despite the great advances in the field of producing activated glass, of determining significance for a number of laser systems are active elements based on monocrystals. A number of new promising crystals are now being developed and produced. Specifically, yttrium aluminate crystals activated by neodymium are a unique laser material in overall dimensions, optical homogeneity, low generation thresholds and generation efficiency which permit investigations in laser spectroscopy and in separation of lithium isotopes.

Among other important cycles of papers devoted to new optical materials must be noted investigations which concern photochrome glass and glass with magnetooptical properties. Essentially important in the field of photochrome glass is transitions from silver- to copper-containing glass. One must understand as of essential importance the undisputable economic advantages and the circumstance that the speed of photochrome processes in copper-containing glass is limited by electron processes rather than ion-diffusion processes, as in silver glass, where the electron stage is obviously only the final stage.

A cycle of many years of investigations in the phenomenon of anion conductivity in glass has now be completed to a large degree. In this regard one can turn attention toward the probability of achieving special photochrome effects in vitreous systems with anion conductivity. Combined control of photochromism by the action of light and electric fields and intensional production of an anion vacancy system are obviously possible in this type of glass.

Photochrome glass has also begun to be used for waveguide development. These waveguides have relatively low attenuation and retain their photochrome properties.

Glass with magnetooptical properties has recently found application in a number of domestic systems, for example, in ring laser gyroscopes. The conditions for the occurrence of groupings of exchange-bound paramagnetic ions and variation of their nature as a function of the composition and heat-treatment conditions of glass were studied to establish the mechanism of formation of ferromagnetism in glass. A material sufficiently transparent in the near IR region of the spectrum and which has superparamagnetic, ferro- and antiferromagnetic properties, has been formed in liquid borate glass with comparatively low concentrations of Fe_2O_3 (3 wt. percent). This effect was used to produce new magnetooptic glass with high Verdet's constant in the near IR region. Specifically, Verdet's constant reaches 1.5 min/cm·E at λ 1.15 microns in borate glass containing small quantities of Fe_2O_3 and MnO, which exceeds by more than an order the corresponding values in glass with rare-earth elements. The ferromagnetic properties of glass are related to formation of manganese ferrite $MnFe_2O_4$. But obviously not all the iron participates in formation of the manganese ferrite; therefore, development of nontrivial methods of concentrating the iron or manganese ions in the glass would permit reduction of its light absorption without reducing the value of Verdet's constant. The discovery of essentially new phenomena of magnetization and magnetic anisotropy for glass may be valuable in development of nontraditional methods of information recording and storage.

Improvement of optical instrument building proceeded until now mainly along the path of increasing the requirements on the quality of optical materials in combination with an increase of their overall dimensions. The main type of effect on the light beam was its refraction on the irregular boundary of an optically dense medium and air. This path is close to its own logical or technical completion. Ever greater attention of materials, scientists and calculators is being turned to materials with properties inhomogeneous in volume, which, for example, makes it possible to focus a bundle of beams after they pass through a flat billet with corresponding distribution of the refractive index. By heat treating a glass billet by the given mode, different for its different parts, one can achieve inhomogeneous distribution of the refractive index, for example, parabolic distribution in the radial direction. However, the modern level of thermal production equipment still does not provide the capability of precisely realizing the necessary gradient. For the time being, among all the methods of forming gradient media, only the method of ion-exchange diffusion from molten salts has found practical application. It is strictly subordinate to thermodynamic principles and is easily realized in manufacture of small-diameter specimens. However, even this method, which utilizes laws of diffusion, has its limitations.

One of the essentially new methods of producing inhomogeneous materials may be the use of space conditions. The gravity gradient through the specimen cross-section may be high due to the proximity of the disturbance sources (operation of the attitude-control engines and the movement of the cosmonauts) at low absolute gravity in a space laboratory. This gradient may be sufficient to differentiate the heavy components of glass and consequently for smooth variation of optical characteristics. It is possible that the use of the weightlessness factor in combination with noncrucible melting will permit manufacture of purer glass than on earth and will make it possible to achieve systems in the vitreous state which are spontaneously crystallized under ordinary conditions.

One can state that glass is the "main building material of optics," as Academician S. I. Vavilov defined it, and also other types of optical media will subsequently satisfy the highest requirements of the calculators and designers of optical systems.

6521
CSO: 8144/0977

SCIENTISTS AND SCIENTIFIC ORGANIZATIONS

SMITRIY PETROVICH VELIKANOV CELEBRATES 70TH BIRTHDAY

Moscow IZVESTIYA AKADEMII NAUK SSSR, ENERGETIKA I TRANSPORT in Russian No 5, Sep-Oct 78 p 174

[Article written on behalf of USSR AS Division of Physical and Technical Problems of Energy and USSR Gosplan Institute of Comprehensive Transport Problems]

[Text] D. P. Velikanov, doctor of Technical Sciences, professor, honored man of science and technology of the Russian Federation, corresponding member of the USSR Academy of Sciences is a great scholar in the field of automotive transportation and transport engineering, a talented teacher who has done much to develop automotive transport science and to train engineering and science cadres.

D. P. Velikanov now works at the Institute of Comprehensive Transportation Problems within USSR Gosplan and supervises research into the future development of means of automotive transportation.

D. P. Velikanov's work activity began as a chauffeur and then as an automobile repair mechanic. Since 1931, when he became an engineer after graduating from Leningrad Polytechnical Institute, in other words for almost 50 years, he has worked continuously in various scientific organizations.

The basic direction of his scientific activity has been the study and improvement of the performance of automobiles to enhance their effective use. In addition to theory, he has filled much of his scientific work with experimental research. As far back as 1933 he took part in organizing and carrying out of tests of the first mass-produced Soviet automobile at the All-Union Karakum Automotive Road Test Institute. While chairing commissions on State testing of new models of domestic automobiles, D. P. Velikanov developed the methodologic foundations of experimental study of automobile and engineer performance in addition to direct supervision of the testing. He brought into practice further road testing under various road and climatic conditions of the country for the State tests.

D. P. Velikanov has authored 140 published works. A significant portion of his published works is related to the study of automobile performance (books published in 1952, 1953, 1956, 1962 and 1977 and many articles). Some works relate to his method of evaluating the effectiveness of automobiles (book "Automobile efficiency," 1969, and others). Based on this research he published a series of works on the requirements for development of automotive constructions and promising standardizations.

While working in the automotive laboratory of USSR Academy of Sciences Institute of the Science of Machines and the Institute of Comprehensive Transportation Problems, under the leadership of D. P. Velikanov was conducted a thorough study of the utilization conditions and efficiency of automotive cargo transport, which established the need for radical enlargement of cargoes and a shift to the mass utilization in the USSR of vehicles with increased unit load capacity.

Considering the country's highway network and its development, recommendations were made for transition to the use of three-axle highway vehicles instead of the dual-axle ones and basic parameters were established for these three-axle vehicles for roads having different maximum axle loads.

The implementation of these recommendations was brought to life by the mass production of three-axle highway-type vehicles. This made it possible to reduce the number of automotive transport workers and all forms of shipment expenditures.

D. P. Velikanov developed a zoning method for the USSR territory according to the climatic zones of automotive exploitation, now the standard. His recommendations for specialization of automotive construction according to natural climate conditions have been adopted and are now being implemented.

D. P. Velikanov has given significant place in his work to research in the field of transport engineering. Under his leadership work has been done to improve engine fuel economy, experimental study of engine operating conditions, using various substitutes for petroleum fuel in engines, the research and development of gas-generating and bottle-gas driven vehicles, the use of electric vehicles, problems of transport engineering, and predicting future development. In recent years, D. P. Velikanov, a member of the USSR Academy of Sciences' Commission Bureau on Hydrogen Energy, lead research into the future promise of transport energy and the use of synthetic fuels and hydrogen for automotive engines.

His research in transportation energy and automotive engines is reflected in his published works.

In addition to scientific and pedagogic activity, D.P. Velikanov has taken an active role in community life. His activity is distinguished by high governmental awards: the Red Banner of Labor and the Badge of Honor, and several medals.

8617
CSO: 1870

PUBLICATIONS

STRUCTURAL REDUNDANCY IN LOGIC MODULES

Moscow STRUKTURNAYA IZBYTOCHNOST' V LOGICHESKIKH USTROYSTVAKH in Russian 1978 15 Oct 77 pp 2, 192

[Annotation and Table of Contents from book by V.A. Malev, Izdatel'stvo "Svyaz'", 2100 copies, 192 pages]

Annotation

[Text] The introduction of structural redundancy permits improvement of various technical characteristics of discrete devices: to raise their reliability, speed, noise immunity, accuracy, to expand functional possibilities, etc. Various aspects of the theory of structural redundancy of discrete devices are considered in the monograph. Examples of structural-redundancy circuits are presented that can be used in switching, digital communications equipment, in control devices and computers, etc. Intended for engineering and technical workers engaged in designing digital equipment.

Table of Contents

8617
CSO: 1870

PUBLICATIONS

THEORY OF RELIABILITY IN RADIO-ENGINEERING SYSTEMS (MATHEMATICAL FOUNDATIONS)

Moscow TEORIYA NADEZHNOSTI RADIOTEKHNICHESKIKH SISTEM (MATEMATICHESKIYE OSNOVY) in Russian 1978 signed to press 29 Dec 77 pp 259-263

[Annotation and table of contents from book by B.R. Levin, Izdatel'stvo "Sovetskoye radio", 23000 copies, 263 pages]

Annotation

[Text] This is a training manual devoted to the mathematical foundation of the theory of reliability of systems. It should aid students in mastering mathematical methods of systems reliability theory which are necessary to the modern engineer in his practical work. The role of mathematical models of breakdowns and recoveries, probability-statistical methods of system structural analysis in the planning stage and data processing in the reliability of a system and its elements, obtained in testing or during operation. Questions of redundancy of systems with and without recovery of breakdown elements are examined. Methods of statistical processing of the results of reliability tests are illustrated by the example of the most common test forms.

Intended for students of radio engineering specialties in pre-diploma courses and in fulfilling diploma projects. Will be useful to a wide range of engineering and technical workers specializing in the field of reliability of radio engineering equipment.

Table of Contents

8617
CSO: 1870

PUBLICATIONS

PHOTOPOTENTIOMETERS AND FUNCTIONAL PHOTORESISTORS

Moscow FOTOPOTENTSIOMETRY I FUNKTSIONAL'NYYE FOTOREZISTORY in Russian 1978 signed to press 20 Jan 78 pp 2, 183-184

[Annotation and table of contents from book by S.V. Svechnikov, A. K. Smovzh and E.B. Kaganovich, Izdatel'stvo "Sovetskoye radio", 9500 copies, 184 pages]

Annotation

[Text] The physical foundations of operation of photopotentiometers and functional photoresistors are presented. Questions of technological realizations of these devices, circuit technique for calculating basic parameters and characteristics are discussed. Designs are cited and questions of using photopotentiometers and functional photoresistors are elaborated.

Methods of production of high-sensitivity photofilms of semiconductor compounds $A^{II}B^{IV}$ are described. Technological processes of forming thin-film structures of photoresistor devices are examined.

Book it intended for experts developing photoelectrical devices. It may be useful to students of senior courses and graduate students specializing in microelectronics, semiconductor devices, automation, and telemechanics.

Table of Contents

8617
CSO: 1870

– END –